RESEARCH

UDOT CONNECTING COMMUNITIES

Utah Department of Transportation-Research Division
4501 South 2700 West, Box 148410 - Salt Lake City, Utah 84114-8410

Report No. UT-07.09

SPATIAL AND TEMPORAL ANALYSES OF WORK ZONE CRASHES AND INVESTIGATION OF RELATIONSHIPS BETWEEN WORK ZONE TRAFFIC CONTROL MEASURES AND CRASH CHARACTERISTICS

Prepared For:

Utah Department of Transportation
Research Division

Submitted by:

Brigham Young University
Department of Civil and Environmental Engineering

Authored by:

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Professor

Thomas G. Jin
Graduate Research Assistant

September 2007

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

1. Report No. UT-07.09	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle Spatial and Temporal Analyses of Work Zone Crashes and Investigation of Relationships between Work Zone Traffic Control Measures and Crash Characteristics	**5. Report Date** September 2007 **6. Performing Organization Code:**	
7. Author(s) Mitsuru Saito, Ph.D., P.E. Thomas G. Jin, Graduate Research Assistant	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address: Brigham Young University Department of Civil & Environmental Eng. Provo, UT 84602	**10. Work Unit No.** **11. Contract No.**	
12. Sponsoring Agency Name and Address: Utah Department of Transportation Research and Development Division 4501 South 2700 West Salt Lake City, UT 84114-8410	**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**	
15. Supplementary Notes:		

16. Abstract

The deterioration of highway infrastructure requires reconstruction, rehabilitation, resurfacing, widening, etc to better serve the users. In order to efficiently and safely manage the traffic for all types of work conditions, appropriate traffic control devices need to be selected for the work zones. Therefore, in order to find relationship between traffic control measures and crash occurrences (crash type and severity level) viewed from both spatial and temporal aspects and to develop a set of guidelines for adopting certain types of traffic control measures given the nature and characteristics of planned work zones, an exploratory data mining for spatial and temporal analyses of work zone crashes, a full-scale data mining and analysis, an aggregated estimation of traffic control cost, and a comparative analysis of the crash characteristics between construction time and non-construction time at the same highway sections were conducted. Based on the findings from these analyses, a set of guidelines for insuring traffic safety in work zones was provided. Some of the findings include the followings: (a) Work zones on urban highways are the most dangerous in terms of crash frequency and rate; (b) Rural highways have larger increase in crash rates in work zones; (c) Primary contributors to work zone crashes had consistent trends – there are more crashes at sections in work zones where alignment, pavement condition, and weather are good; and (d) When crash rates were compared before and during construction at the highway sections where work zones took place, the existence of work zones did not necessarily increased their crash rates.

17. Key Words	**18. Distribution Statement** Available from:
Spatial and temporal crash analysis, work zone safety, traffic control device, data mining, crash characteristics	Utah Department of Transportation Research and Development Division Box 148410 Salt Lake City, Utah 84114-8410 Brigham Young University Department of Civil and Environmental Engineering 368CB Provo, Utah 84602

19. Security Classification (Of this report)	**20. Security Classification (Of this page)**	**21. No. of Pages**	**22. Price**
None	None	311	

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ACKNOWLEDGEMENTS

This research was made possible with funding from the Utah Department of Transportation (UDOT) and Brigham Young University (BYU).

The authors thanks to Doug Anderson, UDOT Research and Development, for his assistance through the course, Technical Advisory Committee (TAC) members, UDOT traffic safety experts and traffic engineers in UDOT region offices for their assistance in collecting data, setting study directions, and commenting on research findings. Special thanks are also due to everyone else at UDOT who helped to complete this research project.

The authors are also thankful to Todd G. Remund, a graduate student in Department of Statistics, and Dr. Denis Eggett of the Center for Statistical Consultation and Collaborative Research of BYU for their assistance in statistical analyses and interpretation of the results.

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1 INTRODUCTION

1.1 Background and Purposes

This study was conducted to meet the goals of three related problem statements presented at the 2005 UTRAC: “Use of Work Zone Crash Histories – Data Mining Project,” “Determination of Crash Costs for Use in Benefit/Cost Analysis,” and “Time Factor in Analysis of Work Zone Related Crashes.” All these three studies require crash records and work zone histories. Hence, it was postulated that by collecting crash data and work zone histories (including traffic control measures used) once, the goals of these three studies could be achieved.

Due to the continual need for upgrades, Utah highways are constantly under maintenance, rehabilitation, and reconstruction work. Safety in work zones is a high priority for the Utah Department of Transportation (UDOT). However, the relationship between work zone crashes and traffic control measures, the relationship between highway improvements and crash reduction rates, and the crash occurrence as a function of the work scheduling have not been clear. Now that UDOT’s CARS website (2006), prepared by the Division of Traffic and Safety, contains crash data covering from year 1992 to year 2005[1], it became possible to conduct an in-depth work zone crash data analysis to provide clues to these issues.

Using basic and advanced statistical procedures, these relationships were analyzed in detail. This report presents the findings and inferences of these analyses. The report also presents a set of guidelines that were developed for selecting proper cost effective work zone traffic control measures.

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[1] This study began in August 2005.

1.2 Objectives

The following objectives were set to achieve the goals of the three problem statements mentioned in the previous section:

- Find relationship between traffic control measures and crash occurrence (type and severity),
- Gather data for conducting cost/benefit comparison of various traffic control measures,
- Find timing for best allocation of traffic safety budgets for work zone traffic safety enforcements, and
- Develop a set of guidelines for adopting certain types of traffic control measures, given the nature and characteristics of work zones

The subsequent chapters of this report present the results of various basic and advanced statistical analyses that were conducted to meet these objectives.

1.3 Organization of the Report

Chapter 1 presents the background and objectives of the study. Chapter 2 summarizes the results of an extensive literature review. The literature review focused on the characteristics of crashes in work zones and the evaluation of traffic control devices in work zones. Especially, crash occurrence or frequency in work zone and sub-work zones and fatal crashes in work zones studied in Texas were reviewed in detail. Also, characteristics of traffic control devices and effects of various traffic control devices were reviewed.

Chapter 3 presents the findings of an exploratory data mining. In the exploratory data mining, a few work zones were selected for an initial analysis. This step was taken to investigate what would be available and how this study could be accomplished. Now that work zone records are typically archived in a few years after this completion, the research team investigated how much of work zone records could be extracted from the archived records. Also gathered in this task were types of work, AADT estimates during construction, beginning and ending mileposts, and other data pertinent to work zones. For these exploratory study sites, crash records were extracted from UDOT's CARS website, prepared by the Division of Traffic and Safety. Crash data were collected for the defined work zone areas of the case study sites for the years beginning 1992 to 2004, which was the range of data that CARS contained at the time of the exploratory data mining. Crash type, severity, location, time, and other pertinent crash data were collected. As part of this task, the selected study sites were visited and pertinent field data were gathered to understand the traffic, geometric, and control conditions of the study sites.

Chapter 4 reports the findings from spatial and temporal analyses of work zone crash data. For these analyses, crash data were grouped into 'before' construction, 'during' construction, and 'after' construction periods. The analyses focused on whether crash potentials for the three periods were similar or different among the three time periods. For the spatial analysis, the locations of crashes were scrutinized to see whether crash potentials had existed before construction and after construction, and to investigate if crash potentials increased during construction at the same locations. The temporal analysis had three aspects. One was to find if there was any tendency of certain locations having crashes over the years regardless the existence of the work zone. Another aspect was to find if any timing of crash coincided with the construction period. The first analysis was to investigate whether certain locations would have crashes regardless the existence of the work zones and the second analysis was to provide clues to effective allocation of traffic safety enforcement budgets during construction. The third aspect of this analysis was to investigate whether highway improvements have actually contributed to the reduction of crashes at the locations where improvements were made. Results of the analysis of the third aspect were to be used for evaluating cost and benefit of highway improvements.

Chapter 5 and 6 report the findings from a full-scale data mining and analysis. The objective of this analysis was modified after the exploratory data mining revealed a lack of construction documents for an extensive analysis. The new approach of using full data mining was requested by the Technical Advisory Committee (TAC) members. Hence, all work zone crash data from 1992 to 2004 were extracted and they were analyzed extensively to find if there were differences in the work zone crash occurrences among the four highway classes (Rural Interstate, Urban Interstate, Rural Non-Interstate, and Urban Non-Interstate) requested by the TAC meeting and UDOT's five crash severity levels (no injury, possible injury, bruises and abrasion, broken bones and bleeding blood, and fatal).

Chapter 7 reports the result of a cost analysis of the two work zones in terms of traffic control costs. Traffic control costs in this study were determined using the data available for the two case study sites which were used in Chapter 4 of this report.

Chapter 8 presents the findings of a comparative analysis of the crash characteristics between construction time and non-construction time at the same highway sections that had been work zones. Two hundred two (202) highway segments that met the data requirements were analyzed in detail. The objective of this analysis was to investigate whether there were any statistically significant differences between the crash rates at the selected highway segments between construction time and non-construction time.

Chapter 9 provides a summary of the findings of all the analyses conducted in the study, including literature review, two case studies, full-scale data mining and analysis, cost analysis of work zones by traffic control cost, and comparative analysis of the crash characteristics between construction time and non-construction time at the same highway sections.

Chapter 10 provides a set of guidelines for ensuring traffic safety in work zones. Several strategies for maintaining traffic safety in work zones were developed based on the findings from the analyses performed in this study. These strategies were divided into two levels: general strategies which are based on the full-scale data mining and analysis, and special strategies which are based on the exploratory data mining and analysis of the two case study sites.

Chapter 11 then presents the conclusions of the study and provides a set of recommendations for the future work.

2 Literature Review

2.1 Characteristics of Crashes in Work Zones

Rouphail et al. (1988) in their Chicago Area Expressway System study using the crash records from 1980 to 1985 showed that the crash rate increased by 88 percent from 0 to 0.219 crashes per mile-day of construction at long-term work zones and by 69 percent from 0 to 0.8 crashes per mile-day of construction at short-term work zones, respectively. They reported a few potential reasons for higher crash rates at short-term work zones such as:

- Discrepancies between the traffic control standards and what was actually in place at work zones were greater at short-term work zones.
- Short-term work zones tend to be in place during off-peak hours, resulting in higher speeds.
- Working during off-peak hours may mean a lower proportion of commuters, which in turn may mean more unfamiliar drivers passing through work zones.
- Rapidly changing work zone layouts in short-term work zones may mean that the traffic control and the location of work zone change often, possibly resulting in driver confusion.

Hall and Lorenz (1989) used contingency tables in order to test the statistical significance of differences between the time and various road conditions using the data from 1982 to 1985 at 114 locations in New Mexico. Bryden et al. (2003) proved that roughly one-third of the crashes involved a vehicle running into (hitting) a traffic control device or other features in work zones in their analysis of 494 crashes in New York from 1994 to 1996.

2.1.1 Crash Occurrences in Work Zones

Many research studies have reported that work zones would be more dangerous than non-work zones. Wilde et al. (1999) summarized the crash occurrences in work zones, as shown in Table 2-1. Crash rates in the work zones evaluated increased by 6.8 percents to 119.0 percents.

Table 2-1 Percentage Changes of Crash Rates in Work Zone

<table>
<tr><th>Project</th><th>Project Site</th><th>% Change in Crash Rate</th></tr>
<tr><td>California</td><td>California</td><td>+21.4 to +7.0</td></tr>
<tr><td>Virginia</td><td>Virginia</td><td>+119.0</td></tr>
<tr><td>Georgia</td><td>Georgia</td><td>+61.3</td></tr>
<tr><td rowspan="5">Midwest Research Institute</td><td>Colorado</td><td rowspan="5">+6.8</td></tr>
<tr><td>Minnesota</td></tr>
<tr><td>Ohio</td></tr>
<tr><td>New York</td></tr>
<tr><td>Washington</td></tr>
<tr><td>Ohio</td><td>Ohio</td><td>+7.0</td></tr>
<tr><td>Rouphail</td><td>Unknown</td><td>+88.0</td></tr>
<tr><td rowspan="3">New Mexico</td><td rowspan="3">New Mexico</td><td>+33.0 (Rural Interstate)</td></tr>
<tr><td>+17.0 (Federal-Aid Primary)</td></tr>
<tr><td>+23.0 (Federal-Aid Secondary)</td></tr>
</table>

Also, Garber and Zhao (2002) evaluated the relationship between the number of crashes and the length of work zone, ADT, and lane width. Equation (2-1) shows a linear relationship that they obtained. Also, Table 2-2 shows percentage differences in crash rates against a combined effect of work zone length and duration based on the equation (2-1). Table 2-2 shows a work zone that is 2 mile-long and last 250 days resulted in the highest difference in crash rates.

$$\text{Number of Crashes} = 0.783 \bullet \text{ADT}^{0.073} \bullet \text{LENGTH}^{0.033} \bullet (\text{WDIFACC} + 1)^{0.05} - 1.33$$

(Equation 2-1)

where,

ADT = average daily traffic,

LENGTH = work zone length, and

WDIFACC = difference between an acceptable width and the existing width.

Table 2-2 Percentage Differences in Crash Rates

Work Zone Lengths (miles)	Duration (Days)								
	100	150	200	250	300	350	400	450	500
0.2	50.96	71.89	79.26	80.70	79.11	75.82	71.53	66.64	61.39
0.4	32.54	52.28	58.81	59.60	54.47	53.73	49.05	43.82	38.25
0.6	30.52	49.56	55.59	56.00	53.56	49.46	44.65	39.21	33.47
0.8	32.99	51.54	57.23	57.36	54.71	50.51	45.44	39.86	33.99
1.0	37.15	55.32	60.73	60.66	57.83	53.49	48.29	42.60	36.63
1.2	42.01	59.86	65.05	64.81	61.84	57.38	52.08	46.30	44.31
1.4	47.13	64.71	69.72	69.33	66.24	61.68	56.29	50.44	44.31
1.6	52.31	69.68	74.52	74.00	70.81	66.17	60.70	54.78	48.60
1.8	57.48	74.63	79.33	78.71	75.42	70.70	65.18	59.19	52.95
2.0	62.56	79.53	84.10	83.38	80.01	75.22	69.64	63.60	57.31

2.1.2 Crash Occurrences in Sub-Work Zones

Garber and Zhao (2002) identified the predominant crash locations within work zones in Virginia highways in their study of 1484 crash reports in Virginia from 1996 to 1999. As shown in Table 2-3, the activity area (actual work area) (70%) had the highest proportion of crashes, followed by the transition area (13%) and the advance warning area (10%).

Table 2-3 Proportions of Crashes in Various Parts of Work Zones in Virginia

Work Zone Area	Number of Crashes at Area	Proportion of Crashes at Area (%)
Advance Warning	149	10
Transition	200	13
Buffer	81	5
Activity	1030	70
Termination	24	2

Wilde et al. (1999) summarized the results of other studies on the distribution of crashes in work zones, as shown in Table 2-4. These studies showed that activity area was the most dangerous. Also, Table 2-5 shows a summary of work zone crashes by zone and other factors. These studies showed that many crashes in work zones took place at night and involved single vehicle and trucks.

Table 2-4 Distribution of Crashes in Work Zone

<table>
<tr><th colspan="2" rowspan="2">Location</th><th colspan="4">Project</th></tr>
<tr><th>Virginia</th><th>Ohio Rural</th><th>Kentucky</th><th>Ohio Turnpike</th></tr>
<tr><td colspan="2">Advance Zone</td><td>12.70%</td><td>15.90%</td><td>5.60%</td><td>6.50%</td></tr>
<tr><td colspan="2">Taper</td><td>13.30%</td><td>22.50%</td><td>7.90%</td><td>9.20%</td></tr>
<tr><td rowspan="2">Work Area</td><td>Lane Closure or Buffer Area</td><td rowspan="2">44.70%</td><td>39.10%</td><td rowspan="2">54.10%</td><td rowspan="2">23.20%</td></tr>
<tr><td>Construction Area</td><td>16.60%</td></tr>
<tr><td colspan="2">Ramp</td><td>0.00%</td><td>3.30%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td colspan="2">Crossover</td><td>0.00%</td><td>0.00%</td><td>0.00%</td><td>34.10%</td></tr>
<tr><td colspan="2">Others</td><td>29.30%</td><td>2.60%</td><td>32.40%</td><td>4.80%</td></tr>
</table>

Table 2-5 Summary of Work Zone Crashes by Zone and Other Factors

<table>
<tr><th rowspan="2">Zone</th><th rowspan="2"># of Crashes</th><th colspan="2">At Night</th><th colspan="2">Trucks at Fault</th><th colspan="2">Injury Crashes</th><th colspan="2">Multiple Vehicle Crashes</th></tr>
<tr><th>No.</th><th>%</th><th>No.</th><th>%</th><th>No.</th><th>%</th><th>No.</th><th>%</th></tr>
<tr><td>Advance</td><td>12</td><td>1</td><td>8.3</td><td>2</td><td>16.7</td><td>3</td><td>25.0</td><td>5</td><td>41.7</td></tr>
<tr><td>Taper</td><td>17</td><td>6</td><td>35.3</td><td>7</td><td>41.2</td><td>3</td><td>17.6</td><td>7</td><td>41.2</td></tr>
<tr><td>Single Lane</td><td>43</td><td>13</td><td>30.2</td><td>23</td><td>53.5</td><td>16</td><td>37.2</td><td>19</td><td>44.2</td></tr>
<tr><td>Crossover</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>First Curve</td><td>49</td><td>34</td><td>69.4</td><td>36</td><td>73.5</td><td>9</td><td>18.4</td><td>9</td><td>18.4</td></tr>
<tr><td>Total</td><td>63</td><td>39</td><td>61.9</td><td>47</td><td>74.6</td><td>11</td><td>17.5</td><td>14</td><td>22.2</td></tr>
<tr><td>Bi-Directional</td><td>41</td><td>18</td><td>43.9</td><td>16</td><td>39.0</td><td>19</td><td>46.3</td><td>22</td><td>53.7</td></tr>
<tr><td>Other Work*</td><td>9</td><td>3</td><td></td><td>1</td><td></td><td></td><td></td><td>2</td><td></td></tr>
<tr><td>Zone Total</td><td>185</td><td>80</td><td>43.2</td><td>96</td><td>51.9</td><td>52</td><td>28.1</td><td>69</td><td>37.3</td></tr>
<tr><td>All Turnpike</td><td>3,429</td><td>1,431</td><td>41.7</td><td>1,915</td><td>55.8</td><td>1,054</td><td>30.7</td><td>1,147</td><td>33.4</td></tr>
</table>

*: Location could not be determined

2.1.3 Fatal Crashes in Work Zones in Texas

2.1.3.1 Work Zone Fatal Crashes by Highway Type

Schrock et al. (2004) compared the distribution of seventy-seven crashes by highway type investigated during their study to the historical crash data gathered from the Texas Crash Database from 1996 through 2001. The comparison of these fatal crashes statistics is shown in Table 2-6. The data indicate that although the total number of crashes that took place at the investigated sites was below the number of crashes at the same locations from 1996 through 2001, the percentages of fatalities that occurred on different highway types are similar to the historical crash data. Based on this apparent consistency, Schrock et al. (2004) concluded that the crashes by highway type that were evaluated in their study were a representative sample of crashes statewide.

Therefore, most of the fatal crashes took place in work zones on interstate highway and US highway. Also, the occurrence weights of fatal crashes in work zones were similar to those of the historical fatal crashes.

Table 2-6 Comparison of Work Zone Fatal Crashes by Roadway Type

Roadway Type	1996		1997		1998		1999		2000		2001		Feb., 2003 - Apr., 2004	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Interstate	39	40	31	29	40	34	34	32	32	27	43	33	24	31
US Highway	21	21	36	33	39	33	32	31	39	32	45	35	26	34
State Highway	17	17	24	22	20	17	20	19	29	24	23	18	16	21
Farm to Market Highway	18	18	17	16	17	14	17	16	21	17	17	13	10	13
Other	4	4	0	0	2	2	2	2	0	0	1	1	1	1
Total	99	100	108	100	118	100	105	100	121	100	129	100	77	100

2.1.3.2 Work Zone Fatal Crashes by Work Zone Location in Texas

Also, Schrock et al. (2004) found that the crash location within a work zone had not been incorporated into the Texas Department of Public Safety (DPS) Crash Database (although it may be estimated from the crash report narrative if the investigating officer included such information). Consequently, such information has not been previously known for Texas work zone crashes. For the crashes examined Schrock et al determined the distribution of crashes within the work zone. The results of the analysis are shown in Table 2-7. For comparison purposes, these results were compared to the results of a previous research completed by the Virginia Transportation Research Council (VTRC) on work zone crashes (not necessarily fatal crashes) on Virginia highways. The designation of buffer area and activity area were grouped together in the study by Schrock et al. (2004), as there was often a blurred boundary between these parts of work zones at several long work zones with the activities spread throughout the length of the work zone.

Table 2-7 Comparison of Work Zone Fatal Crashes by Location with the Work Zone

Work Zone Location	VTRC Research		Data Collection Period Feb.2003 - Apr. 2004	
	No.	%	No.	%
Advance Warning Area	149	10	2	3
Transition Area	200	13	9	15
Longitudinal Buffer Area & Activity Area	1111	75	48	77
Termination Area	24	2	3	5
Total	1484	100	62*	100

Note: * Three non-traffic fatal crash sites and 12 locations where the work zone consisted only of protecting speed limit signs were removed from this analysis

2.1.3.3 Work Zone Fatal Crashes by Work Zone Activity Type in Texas

Schrock et al. (2004) examined the crash sites to determine trends in the type of work activity that was being undertaken at the work zones. Work zone activities included construction, resurfacing, bridgework, maintenance, or other (e.g., traffic signal installations, freeway management system installation, etc.).

These twelve instances are categorized separately in Table 2-8. Table 2-8 shows that many crash data from February, 2003 to April, 2004 happened during a construction activity (35%); however, the highest percentage of work zone in 2001 involved a resurfacing activity (33%).

Table 2-8 Comparison of Work Zone Fatal Crashes by Work Zone Activity Type

Work Zone Activity Type	Investigated Crashes Data Collection Period (Feb.2003 - Apr. 2004)		% of Work Zones by Crash Type, 2001
	No.	%	
Construction Activity	27	35	28
Resurfacing Activity	18	23	33
Bridgework Activity	10	13	15
Maintenance Activity	9*	12	13
Other Activity	1**	1	11
Work Zone in Name Only (No activity)	12	16	
Total	77	100	100

Note: * Including 6 static work zones and 3 moving work zones
** Traffic signal installation

2.1.3.4 Work Zone Fatal Crashes by Lighting Condition in Texas

Also, Schrock et al. (2004) conducted the analysis of crashes by lighting condition to see if there was a predominant period when crashes were more likely.

As shown in Table 2-9, neither daylight nor night conditions appeared to be more likely to be present at the time of a fatal work zone crash. Compared with historical data, this trend during the data collection period for their study seems consistent from 1996 through 2001.

Table 2-9 Comparison of Work Zone Fatal Crashes by Lighting Condition

Lighting Conditions	1996		1997		1998		1999		2000		2001		Data Collection Period 2/03-4/04	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Daylight	50	51	51	47	63	53	51	48	60	50	63	49	35	45
Dawn/ Dusk	3	3	4	4	4	3	4	4	4	3	7	5	2	3
Night	46	46	53	49	51	43	50	48	57	47	59	46	40	52
Total	99	100	108	100	118	100	105	100	121	100	129	100	77	100

2.1.3.5 Work Zone Fatal Crashes Involving Large Truck

Schrock et al. (2004) analyzed the crash data to determine the extent of large truck involvement in fatal work zone crashes. They found that 29 percent of the fatal crashes investigated included a large truck, typically with the truck or passenger cars striking another vehicle or vehicles. As shown in Table 2-10, this value (29%), while at the low end of the range, is also consistent with the values found historically from 1996 through 2001 in the Texas DPS Crash Database.

Table 2-10 Comparison of Work Zone Fatality by Large Truck Involvement

	1996		1997		1998		1999		2000		2001		Data Collection Period 2/03-4/04	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Large Truck Involvement	40	40	32	30	32	27	42	40	50	41	46	36	22	29
No Large Truck Involvement	59	60	76	70	86	73	63	60	71	59	83	64	5	71
Total	99	100	108	100	118	100	105	100	121	100	129	100	77	100

2.1.3.6 Other Researches Related to Fatal Crashes

Daniel et al. (2000) evaluated all fatal work zone crashes (181 crash reports in Georgia from 1995 to 1997) to survey where and in what condition fatal crashes took place. They found the following:

- 30% of all fatal crashes took place while work was in progress,
- 50% of all fatal crashes took place when work zone was idle,
- 49% of all fatal crashes involved single-vehicle crashes,
- 20% of all fatal crashes involved heavy trucks, and
- 13% of all fatal crashes took place outside the work zone.

Fatal crashes in work zone were more likely to involve a collision with another object, including other vehicles, equipment, and traffic control devices.

2.1.4 Section Summary

Many studies discussed the characteristics of various crashes in work zones. Understanding the characteristics of crashes in work zones and the countermeasures against them is an essential process for augmenting traffic safety in work zones. In order to clearly understand the reasons for having crashes in work zones, Mercier (1994) built five prototypical scenarios where work zone crashes may occur:

1. Misunderstanding by motorists about the expected path through the work zone,
2. Motorist surprised by the work zone's presence or by an obstacle in the work zone,
3. Motorists surprised by an unusually complex situation in the work zone,
4. Longer reaction time needed by the motorist to react to a queue before or in the work zone, and
5. Motorist losing control of her/his vehicle due to unsafe pavement conditions (oil, gravel, etc.)

2.2 Evaluation of Traffic Control Devices in Work Zones

2.2.1 Characteristics of Traffic Control Devices

Carlson at al. (2000) summarized the characteristics of traffic control devices used in work zones by reviewing past research studies. Table 2-11 shows the measures that were determined to be of high priority and Table 2-12 shows the measures that were considered to be of low or medium priority to the Texas Department of Transportation.

Table 2-11 High Priority Traffic Control Measures

Item	Advantages	Disadvantages
Larger/Fluorescent Signs	- Improved visibility - Easy for workers to set up and remove	- Hard to quantify impact
High-visibility Clothing	- Improved nighttime visibility - Orange clothing may blend in with work zone background	- Solid fabric vests are more visible, but less likely to be worn during warm weather
Opposing Traffic Lane Dividers (OTLD)	- Can be used as a temporary centerline - Proven effective in other states	- Some states have experienced problems with OTLD's staying update - Limited application
Portable Changeable Message Signs	- Flexible device with multiple application - Can increase preparatory merging and decrease speeds	- Lengthy setup - Expensive
Portable Rumble Strips	- Combination of tactile and auditory stimulus commands attention	- Problems with deploying and handling strip - Problems with having strips stay in place - Some drivers avoid strip, thinking that it is debris in road
Radar Drone	- Tends to impact vehicles traveling at highest speeds - Vehicles with detectors may slow down surrounding vehicles - Trucks with CB radios relay information to other trucks in area	- Repeated use may lose effectiveness if no enforcement is present - Sudden braking can lead to vehicle conflicts
Radar Speed Display	- Radar signal and visual display help reinforce speed limit - Possibility of implied photo-enforcement	- Expensive - Some drivers may accelerate past display to see speed increase
Sign Attachments	- Helps draw attention to sign	- May lose effectiveness over time
Temporary Stop Bar	- Designers stopping point for vehicles at flagging station	- Anchoring of stop bar may be Problematic
Vehicle Visibility Improvement	- Improved vehicle visibility at night	- Additional cost for vehicles

Table 2-12 Low and Medium Priority Traffic Control Measures

Item	Advantages	Disadvantages
Direction Indicator Barricades	- Provides more guidance than barrels or cones	- Greater potential for misapplication
Flashing Stop/Slow Paddle	- Lights improve paddle visibility - Approved by national MUTCD	- Battery replacement may be frequent
Intrusion Alarm	- Alerts workers to vehicles entering work area	- Only appropriate for stationary work zones - Susceptible to false alarms - Very long setup times and expensive
Lane Narrowing	- Speed reductions are possible	- Potential increase in side swipe crashes
Portable Traffic Signal	- Drivers are familiar with device	- Battery replacement costly - May disrupt downstream intersection operations - Drivers may brake severely or run light if it is not expected
Queue Length Detector	- Provides information stopped traffic, allowing drivers to slow down or choose alternate route	- Problems with false alarm - Cellular communications can cause problems during peak hours
Remote Driven Vehicle	- Improved safety during moving maintenance operations	- Expensive - Technology requires extensive training
Water-Filled Barrier	- Water absorbs majority of crash impact - NCHRP 350 approved for up to 62mph	- Standard size water truck can only fill three barrels - Antifreeze must be added in winter months - Mixture must be pumped out when the barrier is moved for environmental reasons - Durability is still a question - Spilled water after impact can create potentially dangerous conditions

2.2.2 Effects of Various Traffic Control Devices

2.2.2.1 Innovative Traffic Control Devices for Use in Short-Term Maintenance Work Zones

Fontaine et al. (2000) reviewed the innovative traffic control devices in order to determine which devices may be appropriate. As a result of the literature review, they selected nine traffic control devices for evaluation. Out of nine selected, six traffic control devices were evaluated as shown in Table 2-13.

Table 2-13 Summary of the Effects of Traffic Control Devices

Devices	Effects
Speed Display Trailers	- Reduced average speeds by 5 mph in the work zone - Reduced percent of vehicles exceeding speed limit - Positive worker comments
Portable Variable Message Signs (VMS)	- Produced 1-2 mph reduction in average speed in the work zone - Half as many cars were in the closed lane approximately 1000 ft from the work zone taper when the VMS was active
Fluorescent Yellow-green Worker Vests and Hard Hat Covers	- Fluorescent yellow-green garments are more visible than orange garments against common work zone backgrounds - Fluorescent yellow-green garments have a greater luminance (brightness) than orange garments
Fluorescent Orange Sign	- Positive comments from workers and drivers on increased visibility of signs - Primary benefits of fluorescence occurs at dawn and dusk
Radar Drone	- Produced a 1-2 mph reduction in average speed - Easy to implement
Retro-reflective Vehicle Visibility Improvement	- Positive comments from workers on visibility of flagger vehicle - Primary benefit would occur at night

2.2.2.2 Dynamic Speed Display Signs (DSDS)

Dynamic speed display signs (DSDS) detect and display a vehicle's current speed back to the driver. They have shown to have a significant speed-reducing effect in temporary applications such as work zones or neighborhood speed watch programs.

Rose et al. (2003) found out that overall, average speeds were reduced by 9 mph at the school speed zone. Elsewhere, the effect of the DSDS was less dramatic, with average speeds reduced by 5 mph or less, depending on the location tested. As expected, the influence of a DSDS was found to differ depending on how fast a motorist approached the DSDS. Those motorists traveling faster than the posted speed did appear to reduce their speed more significantly in response to the DSDS than did motorists traveling at or below the posted speed limit. The results of this project suggest that DSDS can be effective at reducing speeds in permanent applications if the site conditions apply appropriately. Figure 2-1 shows a sample of DSDS.

Figure 2-1 Example of a Portable Dynamic Speed Display System for Work Zones

Controlling traffic in work zones to improve safety has long been a major concern for highway agencies. Shaik et al. (1998) tested for the effectiveness of traffic control devices in improving merging and diverging speed and reducing speed variance at an interstate highway work zone in Missouri, including white lane drop arrows, orange rumble strips, and the CB wizard alert system. Results of implementing the white lane drop arrows and the CB wizard alert system indicated decreases in the percentage of vehicles in the closed lane, mean speed, and speed variance. Table 2-14 shows the detailed test results.

Table 2-14 Percent Changes in the Number of Vehicles in the Closed Lane

Vehicle Type	Time	Traffic Control Devices		
		White Lane Drop Arrows*	Wizard System#	CB Wizard Alert System and Orange Rumble Strips#
All Vehicle	Day	-1.7 (20.8)	-2.9 (15.8)	+0.13 (2.95)
	Night	-1.4 (7.1)	-3.1 (7.5)	-2.0 (11.7)
Passenger	Day	-1.8 (21.7)	-1.8 (12.0)	+1.44 (1.78)
	Night	-1.7 (22.5)	-0.3 (0.3)	-1.5 (10.6)
Non-Passenger	Day	-1.0 (32.0)	-4.4 (29.8)	+0.1 (12.25)
	Night	-1.8 (17.8)	-6.2 (44.0)	-2.5 (11.5)

* White lane drop arrows and the CB wizard alert system were compared to no devices; the CB wizard
alert system and orange rumble strips were compared to the CB wizard alert system alone
The first number represents the percentage change of 2-lane flow, or the change in the closed lane's share
of all traffic; the second number in parentheses represents the percentage change within the closed lane.
For example, if each lane carried 50 vehicles before and the closed lane carried no vehicles after, the cell
would have the value - 50 (100) both in percentage

Maze et al. (2000) surveyed the effect of speed reduction systems to employees working in state agencies in order to evaluate the work zone speed reduction measures. Table 2-15 shows the survey results of work zone speed reduction measures.

Table 2-15 Survey Results of Work Zone Speed Reduction Measures

Speed Reduction Measures	Speed Reduction		No Information	Not Applicable
	Yes	No		
Mobile Maintenance Operation (Two-lane Road)	11	18	9	1
Mobile Maintenance Operation (Multilane Road)	10	24	5	0
Lane Closure with No Concrete Barrier (Multilane Road)	32	2	5	0
Lane Closure with Concrete Barrier (Multilane Road)	33	1	5	0
Lane Closure on a Structure with Concrete Barrier (Multilane Road)	33	0	6	0
Lane Shift (Multilane Road)	27	4	6	2
Median Crossover (Multilane Road)	30	0	9	0

Also, they surveyed speed reduction strategies and effects. Table 2-16 presents the number of respondents on the applicability and effectiveness of each strategy. The values in the second and third columns in each row add up to 34 agencies. The numbers listed in the third column are also sums of the values listed in each row of the last four columns. For example, 28 agencies (see Table 2-16, first row) indicated using regulatory speed limit signs as a strategy to reduce speeds at their work zones. Of these 28 agencies, two agencies perceived the strategy to be effective, seven agencies indicated that it is ineffective, ten agencies reported that the strategy is partially effective in reducing speeds at work zones, and nine agencies provided no information on the system's effectiveness.

Table 2-16 Speed Reduction Strategies and Their Effectiveness

	Applicable		Effective	Ineffective	Partially Effective	No information
	No	Yes				
Regulatory signs	6	28	2	7	10	9
Advisory signs	26	8	2	0	3	3
CMS	16	18	4	2	5	7
Police enforcement	8	26	18	0	5	3
Ghost police car	32	2	1	0	1	0
Flaggers	32	2	2	0	0	0
Speed display	28	6	2	1	2	1
Drone radar	28	6	2	1	2	1
Rumble strips	33	1	0	0	1	0
Lane narrowing	31	3	2	0	0	1
Pavement markings	33	1	0	0	0	1
HAR	32	2	0	0	1	1

2.2.3 Section Summary

Quantifying the effects of traffic control devices is difficult at best because the purpose of setting traffic control devices in work zones is to better manage traffic flow and improve safety. The choice of a traffic control device depends on the characteristics of the projects such as traffic control budget, construction time, construction duration, construction location, etc. Traffic engineers also want to get maximum effects of traffic control devices with minimum investments.

There have been several research studies on estimating the effects of traffic control devices in work zones, but they were limited to a few special devices. A short summary of the effects of traffic control devices is shown in Table 2-13 and the results of an opinion survey of state transportation engineers on traffic control devices in work zones are shown in Table 2-16.

2.3 Chapter Summary

Deterioration of highway infrastructure requires reconstruction, rehabilitation, resurfacing, widening, etc., to better serve the drivers. In order to efficiently and safely manage the traffic for all types of work conditions, appropriate traffic control devices need to be selected. According to the Manual on

Uniform Traffic Control Devices (MUTCD, 2003), work zones are divided into five sub-areas consisting of 1) advanced warning area, 2) transition area, 3) buffer area, 4) activity area, and 5) termination area. (Refer to Appendix A.1)

According to previous research studies, crash rates in work zones tend to increase compared to non-work zone sections. Most crashes (10% of them) tend to happen in the activity area among the five work zone sub-areas. Daniel at el. (2000) evaluated fatal crash reports from 1995 to 1997 in Georgia to identify where and in what condition fatal crashes happened. They found the following; 1) 30% of fatal crashes happened while work was in progress, 2) 50% of them took place when work zone was idle, 3) 49% of all fatal crashes involved single-vehicle crashes, and 4) 20% of fatal crashes involved heavy trucks and 5) 13% of fatal crashes took place in non-work zones. They also found that fatal crashes in work zones were more likely to involve a collision with objects, including other vehicles, equipment, and traffic control devices.

As for night work, feasibility and suitability of night work must be evaluated in advance, including traffic condition (congestion, safety, and traffic control), construction condition (productivity and quality), social condition (workers physical condition and relationship with the family and the society), economic condition (construction costs, user costs, and accident costs), environmental (air quality and fuel consumption) and other relevant conditions (public relations, scheduling). (Refer to Appendix A.2)

Ullman et al. (2004) assessed the safety impacts of active night work zones in Texas, and reported that crashes during night time work were higher than those during day time work. Additionally, they found that at night, the percent of severe crashes was actually slightly less overall during the project on both nights of activity and nights without activity, when compared to the before condition in the some highway sections. (Refer to Appendix A.2)

The quantification of the effects of traffic control devices is difficult at best because the purpose of setting traffic control devices in work zones is to better manage traffic flow and improve safety. The choice of a traffic control device depends on the characteristics of the projects such as traffic control budget, construction time, construction duration, construction location, etc and not necessarily on the effectiveness of control devices. Traffic engineers want to get maximum effects of traffic control devices with minimum investments. There have been several research studies on estimating the effects of traffic control devices in work zone, but they were limited to a few selected devices and the effects of traffic control devices are not definitive.

ITS technologies have increasingly been used to anticipate and mitigate congestion caused by highway work zones. These technologies provide ways to better monitor and manage traffic flow through work zones and increase safety in work zones. Case-based reasoning (CBR) system, real time work zone traffic control system, work zone travel time system, and traffic incident management programs for work zone are some of the ITS technologies applied to work zone. In order to better control and keep smooth traffic flow through work zones and improve safety for both workers and road users, proactive use of ITS advanced technologies is recommended. (Refer to Appendix A.3)

3 Exploratory Data Mining

3.1 Methodology

Data mining (DM), also called Knowledge-Discovery in Databases (KDD) or Knowledge-Discovery and Data Mining (KDDM), is the process of searching large volumes of data for patterns using tools such as classification, association rule mining, clustering, etc. It involves sorting through large amounts of data and selecting relevant information. It is usually used by businesses and other business related organizations, but is increasingly used in sciences to extract information from the enormous data sets generated by modern experimentation.

Data are often expressed in a condensed data mine-able format, or one that facilitates the practice of data mining. Common examples include executive summaries and scientific abstracts. Data mining identifies trends within data that go beyond simple analysis. Through the use of sophisticated algorithms, users have the ability to identify key attributes of business processes and target opportunities.

Briefly stated, data mining is the discovery of potentially useful patterns in the data that were previously unknown. An analyst approaches the analysis of a set of data with minimal expectations. However, some ideas in which the analyst is interested in helping him focus the search. However, he needs to beware of the trap of mining the data until he gets the results he hopes for. Figure 3-1 helps illustrate this process using a flow chart of a typical data mining.

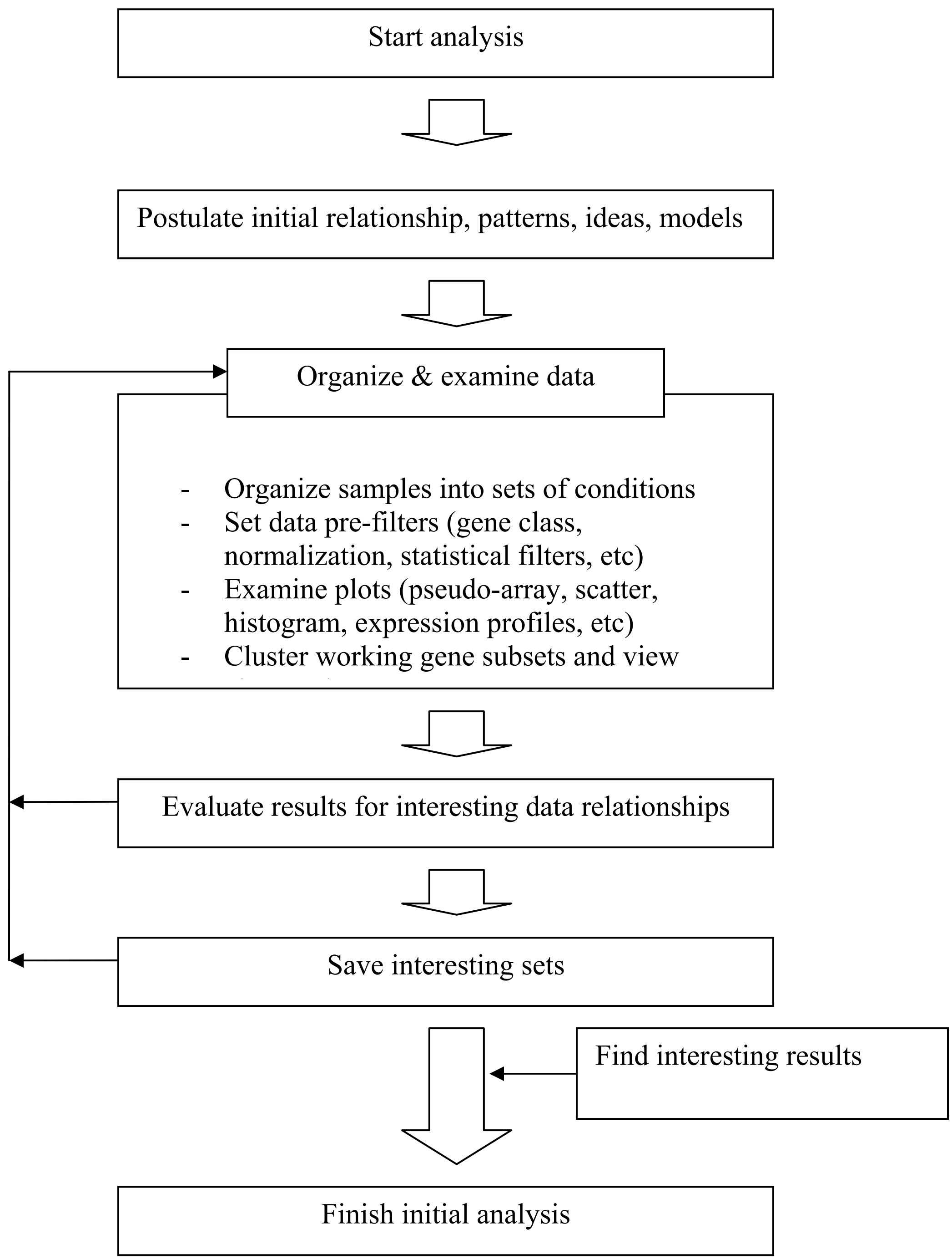


Figure 3-1 Flow Chart of a Typical Data Mining

3.2 Data Collection

3.2.1 Process of Choosing Projects

In order to efficiently and systematically collect appropriate data for this project, several case study sites were selected through the following selection process shown in Figure 3-2.

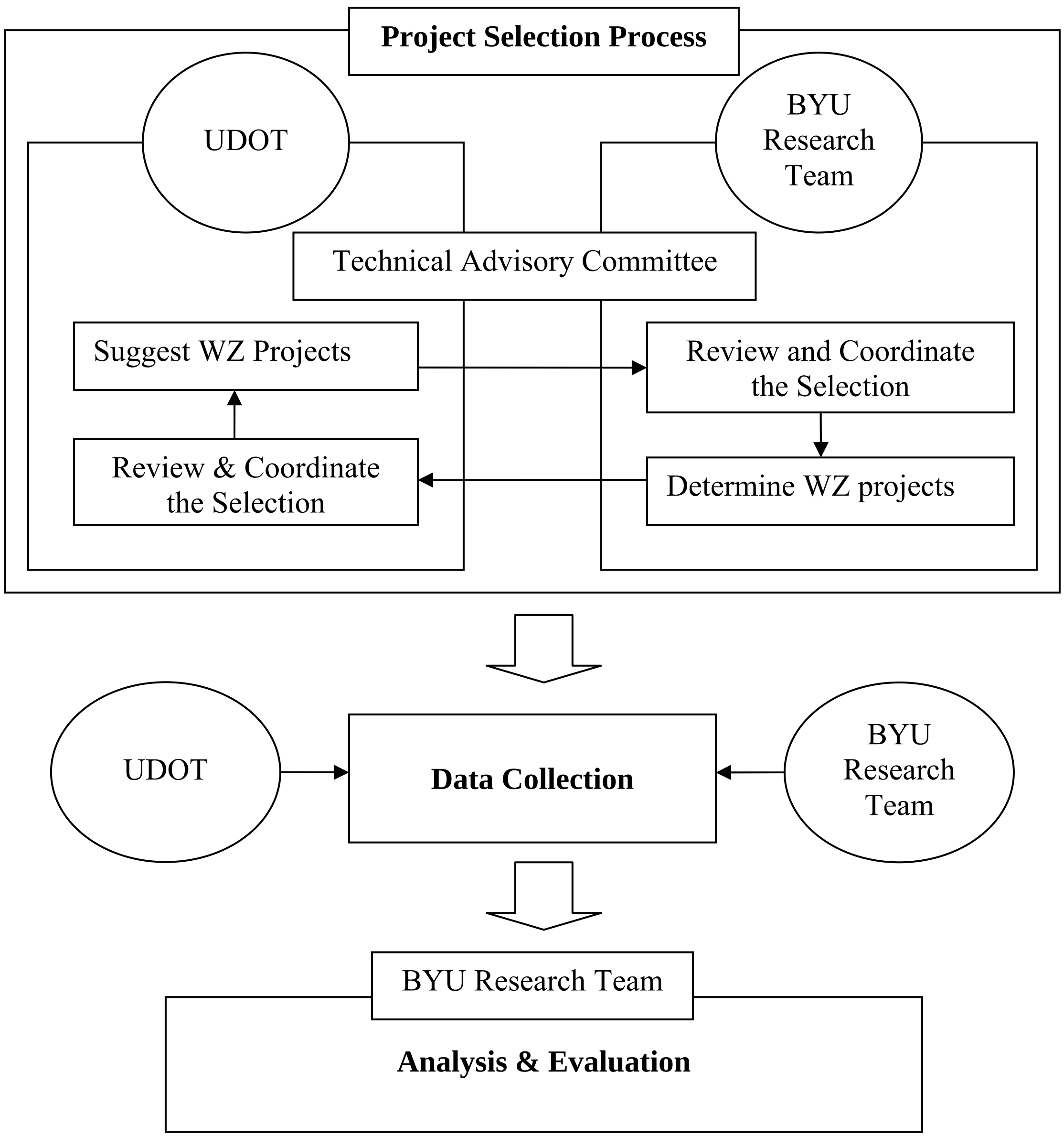


Figure 3-2 Processes of Project Selection and Data Analysis

3.2.1.1 Initial Listing of Case Study Sites

As soon as this project began, a Technical Advisory Committee (TAC) was organized. The members of the TAC consisted of a UDOT project manager, traffic engineers in UDOT region offices, and the BYU research team. The first TAC meeting was held in August 24, 2005 in order to discuss the scope of the project, the availability of data, and the choice of the case study sites.

In the first TAC meeting, sixteen projects in the four UDOT regions in Table 3-1 were suggested and discussed as potential case study sites.

Table 3-1 Case Study Sites Suggested in the First TAC Meeting

No	Location of Work Zone	Region
1	I-15 106th to 5th north (before the Olympics), 1997-2001. In this analysis, investigate also the effect of the I-15 work zone on arterial projects parallel with I-15	Region 2
2	I-15 Provo area rehabilitation work	Region 3
3	I-215 between redwood and I-15	Region 2
4	US 6 between Spanish Fork and Price, passing lane addition	Region 3
5	Redwood road work zones	Region 2
6	Provo canyon	Region 3
7	Logan canyon	Region 1
8	Wall Ave. between 22nd and 31st in Ogden	Region 1
9	Reconstruction of St. George Blvd	Region 4
10	Orem NB State St., Storm drain issues	Region 3
11	Redwood road between 70th and 94th, then 94th and 104th	Region 2
12	I-15 Lehi area, adding a lane, night work	Region 3
13	I-15 south of Nephi, reconstruction work, day work, to the Sevier river (Barrier separation used)	Region 3
14	I-15 near Parowan	Region 4
15	I-84 between Mt. Green and Morgan (Barrier separation used)	Region 1
16	104th/106th St. between I-15 and Redwood Rd.	Region 2

3.2.1.2 *Final Selection of Case Study Sites*

As seen in Figure 3-2, TAC members representing the four UDOT regions were contacted and they provided the BYU team a list of projects that may be used for an exploratory analysis. Thirteen case study sites were finally selected through the feedback process between the research team and the TAC members. Table 3-2 shows these 13 case study sites.

Table 3-2 Case Study Sites for Data Collection

Region	Project Name (Construction Type)	Duration	Location	Resident Engineer	Project Inspector
1	Logan Canyon Summit to Garden City	Summer of 05 and 06	US-89 near Garden City	Nick Peterson	Gary Nelson
1	Mt. Green interchange to Morgan I-84 East of Ogden	05/15/2004-08/16/2005	Morgan area on I-84	Steven Niebergall	Todd Straw
2	I-15 from 10800 S to 500N (Reconstruction, widening)	4/16/1997-10/15/2001	I-15, 10800S to 500N	Bob Whitehead	Barney Bekkemellom
2	I-215, 5200S to 5400S (Autumn Park Dr.) (Noise walls)	9/1/1999-5/31/2001	I-215, 5200S to 5400S	Betty Purdie	Rick Rhodes
2	Redwood Rd. 9000 S to 7800S (Road widening)	4/14/1997-8/3/1999	Redwood Rd., 9000S to 7800S	Rick Campagna	John Phippen
2	SR-68, Redwood Rd. 14400S to 10400S (Plant mix seal coat)	4/30/2001-12/1/2001	Redwood Rd. 14400S to 10400S	Steve Park	Not Found
2	10400S, Redwood Rd. to I-15 (Roto mill and plant mix seal 11 locations)	5/2/1997-11/1/1998	10400S, Redwood Rd. to I-15	Kris Peterson	Steve Nielson
3	I-15, University Ave. interchange mod., new interchange & widening	03/2000-11/2001	Utah County	Greg Searle	Degen Lewis
3	SR-6, Spanish Fork Canyon safety Improve.	04/2002-8/15/2003	Spanish Fork Canyon	Jim Golden	Gary Gibbs
3	SR-189, Provo Canyon, Wildwood to Deer Creek Ames const.	12/2004-present	Wasatch County	Jim Golden	Gary Gibbs
3	State St. 100 N to 800 N	07/05/2005-06/2006	Orem, NB State St.	Ryan Clark	John Writhlin
3	I-15, Corridor in Utah County (Widening)	06/02/2005-07/2006	Lehi, Utah County	Greg Searle	Andy Anderson
3	I-15, Sevier River Northward (Reconstr.)	04/2002-06/2003	Juab County	Greg Searle	Andy Anderson

3.2.2 Data Collection

3.2.2.1 General Data Collection

The BYU research team contacted resident engineers and inspectors for the projects that were chosen for the exploratory analysis. With the help of the resident engineer and the project inspector of each case study site, the research team completed interviews seeking for relevant data for the case study sites in Region 1 and Region 3. However, as it turned out, finding the resident engineers or the inspectors who were involved in the selected projects in Region 2 was difficult and the research team was not able to conduct interviews for the Region 2 study sites. Therefore, the research team visited the library archives of UDOT where the documents of all projects executed by UDOT were stored. Data sufficient for intended analyses were not available because the engineering document boxes of all projects in Region 2 were destroyed within three years after the completion of projects. In order to achieve the goal of this study, detailed traffic control plans, traffic devices, and crash data were needed. Data for the projects in Region 2 were incomplete as shown in Table 3-3.

Table 3-3 Review of the Availability of Project Data for Region 2 Study Sites

Classification Number	Project Number	Project Name (Construction Type)	Interview	UDOT Library			Crash data	Possibility of Analysis
				Files	Plans	Engineering Box		
2_I-15_1SLC	SP-15-7(135) 296	I-15, 10800S to 500N (Reconstruction, widening)	No	Yes	No	No	Yes	No
2_I-215_2SLC	SP-215-9(21)3C	I-215,5200S to5400S (3 Noise Walls)	No	Yes	No	No (Destroyed June 2004)	Yes	No
2_US-68_3SLC	SP-0068 (9)47	Redwood Rd., 9000S to7800S (Widening)	Yes	Yes	Yes	No (Destroyed July 2004)	Yes	No
2_US-68_4SLC	SP-9999 (583)A	SR-68, 11400S to 10400S (Plant mix seal coat)	No	Yes	No	No (Destroy March 2002)	Yes	No
2_US151_5SLC	SP-9999 (424)B	10400 S, Redwood Rd. to I-15, (Roto mill and plant mix seal 11places)	No	No	No	No	Yes	NO

3.2.2.2 Interview Topics

In order to efficiently analyze the data of the proposed case study sites, interviews were conducted with the resident engineer or the project inspector of each case study project. Main topics of the interviews included the outline of project; construction type and cost; traffic control plans and devices; traffic condition before, during, and after construction; crash history during construction; road way types; and other relevant topics. Appendix B shows the entire list of interview questions. The following list shows a summary of the interview questions:

- Project Outline: project name, project location, project duration, project executor, road type and geometric condition, project manager (region), and total cost;
- Construction Type and Cost: construction type, construction scale, detailed location information of construction, construction schedule construction phases, construction cost categories, and man-powers;
- Traffic Control Plans and Devices: traffic control plans by phase or by time, work zone traffic control plan, traffic control devices, and special traffic control devices and measures used for maintaining safety through work zones;
- Traffic Condition Before, During and After Construction: speed limit difference, traffic volume, delay, travel time, operating speed, and special driver behavior;
- Crash History during Construction: total number of crashes, crash types, location and time, surface condition, number of vehicles involved in a crash, vehicle operating speed, crash severity, and relationship with the work zone or workers; and

- Others: engineer's construction diary, shortage of original documents (region or archive), special advice and recommendation for work zone traffic safety, and special memos, if any.

3.2.2.3 Crash Data

Crash data used in this study were extracted from UDOT's CARS website. (2006) Note that all crash rates of 'before' and 'after' periods mentioned in this chapter are annual average crash rates of the number of years used for the analysis before or after the construction. The typical recommended number of years of a safety study related analysis period for the 'before' and 'after' is three years. However, due to the insufficient dataset available at the time of the study for either before or after period, rigorous statistical inferences could not be made; in some cases only two years of data were available at the time of the study. The findings presented in this report, therefore, should be interpreted with caution.

3.3 Chapter Summary

Collected crash data were sorted, summarized, and analyzed by using Microsoft Office Excel 2003®. Two case study sites were chosen through an exploratory data mining process. General and special crash analyses by direction, construction phase, and season of the two study sites were performed. The analysis results of the two case studies were summarized in terms of crash rate versus contribution factors such as light condition, traffic control measure, alignment, weather condition, surface condition, etc. The detailed resulted of the analysis can be found in Chapter 4. Spatial and Temporal Analyses of Work Zone Related Crashes.

4 Spatial and Temporal Analyses of Work Zone Related Crashes

Based on the findings presented in Chapter 3 Exploratory Data Mining, two work zones that had different main traffic control devices were chosen. One of the work zones had barrels as its major control device (on US-6, south of Spanish Fork), while the other had concrete Jersey barriers as its main traffic control device (on I-15, south of Payson). This chapter presents the results of spatial and temporal analyses of work zone related crashes of these two work zones.

The following general and special crash analyses by direction, phase, and season were carried out:

- Spatial and temporal crash rates by severity,
- Comparison of spatial and temporal crash rates by mile post in the work zone,
- Monthly crash rates during construction,
- Crash rates by severity and light condition,
- Crash rates by traffic control,
- Crash rates by alignment,
- Crash rates by weather condition
- Crash rates by surface condition, and
- Crash rates by crash type.

4.1 Description of Two Case Studies

4.1.1 Case I: US-6 from MP 196.79 to MP 200.51, South of Spanish Fork

4.1.1.1 Project Outline

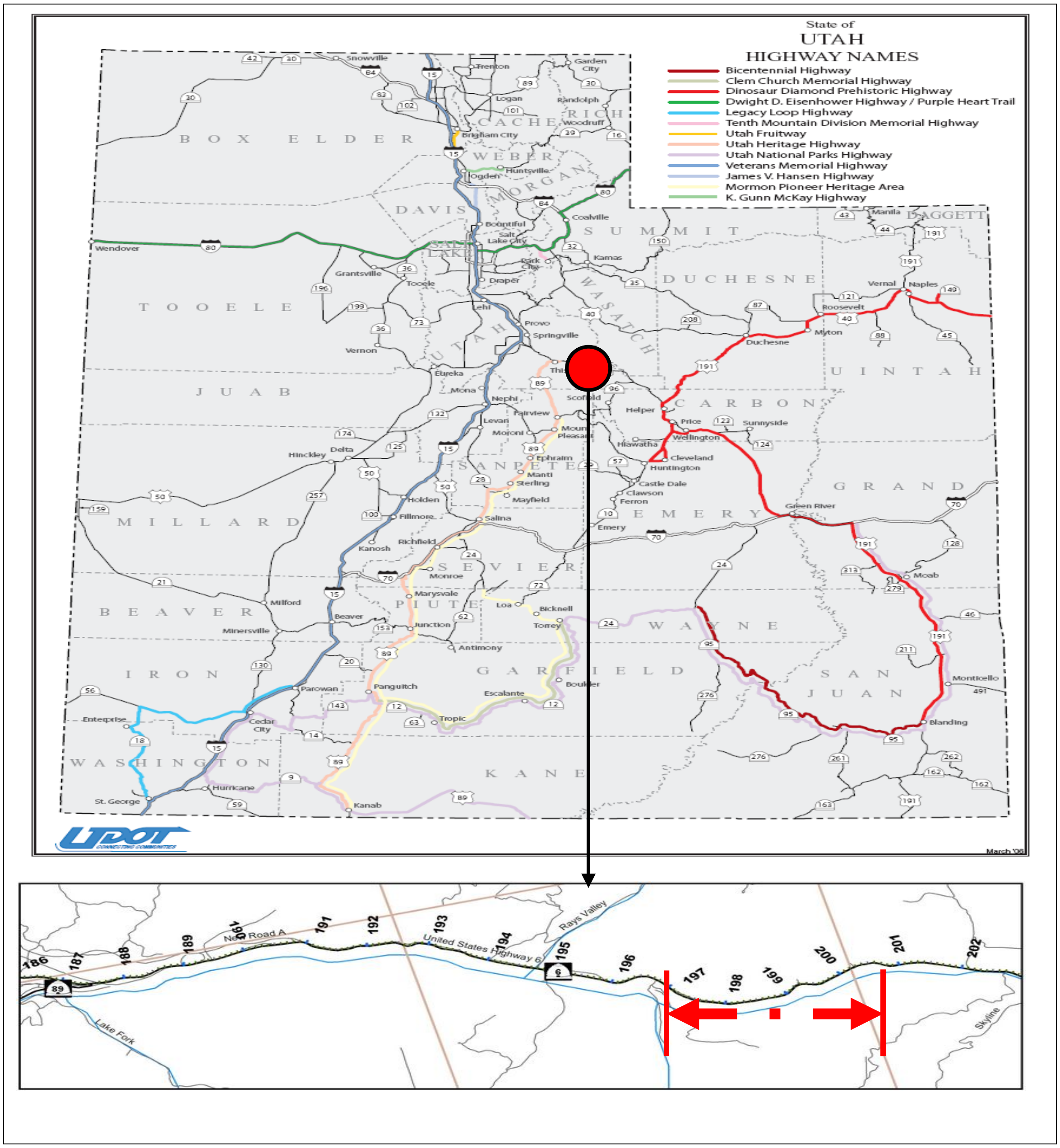
The first case study site was called "Spanish Fork Canyon Safety Improvements" on US-6, which is a major rural arterial connecting such cities as Spanish Fork, Price, and Green River in Utah. The work zone spanned from mile post (MP) 196.79 to MP 200.51, 3.72 miles in length. Main works of this project included rehabilitation and reconstruction including widening, hot-mix asphalt paving, and chip seal. These works were done in the second lane of the highway and roadsides.

Total cost of this project was about 10.8 million dollars (UDOT, 2002). Traffic control cost was 150,000 dollars, which accounted for 1.4% of the total construction cost. Construction began in April, 2002 and finished in August, 2003 at this site.

Figure 4-1 shows the location of the Case I work zone from MP 196.79 to MP 200.51 on US-6. This work zone was located about 12.5 miles south of Spanish Fork.

4.1.1.2 Crash Data

Crash data were grouped into three time periods: before, during, and after construction. Crash data for three years from April 1999 to April 2002 were used for the 'before' period, crash data for 17.5 months from April 2002 to August 15th of 2003 for the 'during' period, and crash data for 16.5 months from August 16th of 2003 to December of 2004 for the "after" period respectively.



* Source: UDOT Website: http://www.udot.utah.gov (2007)

Figure 4-1 Map of Case I: US-6 from MP 196.79 to MP 200.51 (US-6 Site)

Table 4-1 shows crash rates by severity for the 'before', 'during', 'after' analysis period. Annual average crash rates and crash rates per 100 MVMT (100 Million Vehicle Mile Traveled) decreased as the analysis period progressed through 'before', 'during', and 'after' analysis period. The annual average crash rate and crash rate per 100 MVMT in the 'before' period were 22.00 per year and 244.61 per 100 MVMT, respectively. The annual average crash rate and crash rate per 100 MVMT in the 'during' period were 19.35 per year and 210.80 per 100 MVMT, respectively. And, the annual average crash rate and crash rate per 100 MVMT in the 'after' period were 6.00 per year and 66.88 per 100 MVMT, respectively. It appears that this construction significantly helped reduce crashes in this stretch of US-6. Note that due to the duration of the construction and the availability of 'after' data, the reader should be cautious about this outcome. As shown in Table 4-1, the rate of fatal crash was the highest during construction (8.43 crashes per 100 MVMT).

Table 4-1 Crash Rates by Severity in the 'Before', 'During' and 'After' Construction (US-6 Site)

	Before			During			After		
	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT
No Injury	29.00	9.67	107.48	20.00	15.48	168.64	14.00	10.50	117.04
Possible Injury	17.00	5.67	63.01	2.00	1.55	16.86	0.00	0.00	0.00
Bruises and Abrasion	11.00	3.67	40.77	1.00	0.77	8.43	1.00	0.75	8.36
Broken Bones or Bleeding Blood	8.00	2.67	29.65	1.00	0.77	8.43	2.00	1.50	16.72
Fatal	1.00	0.33	3.71	1.00	0.77	8.43	1.00	0.75	8.36
Total	66.00	22.00	244.61	25.00	19.35	210.80	18.00	6.00	66.88

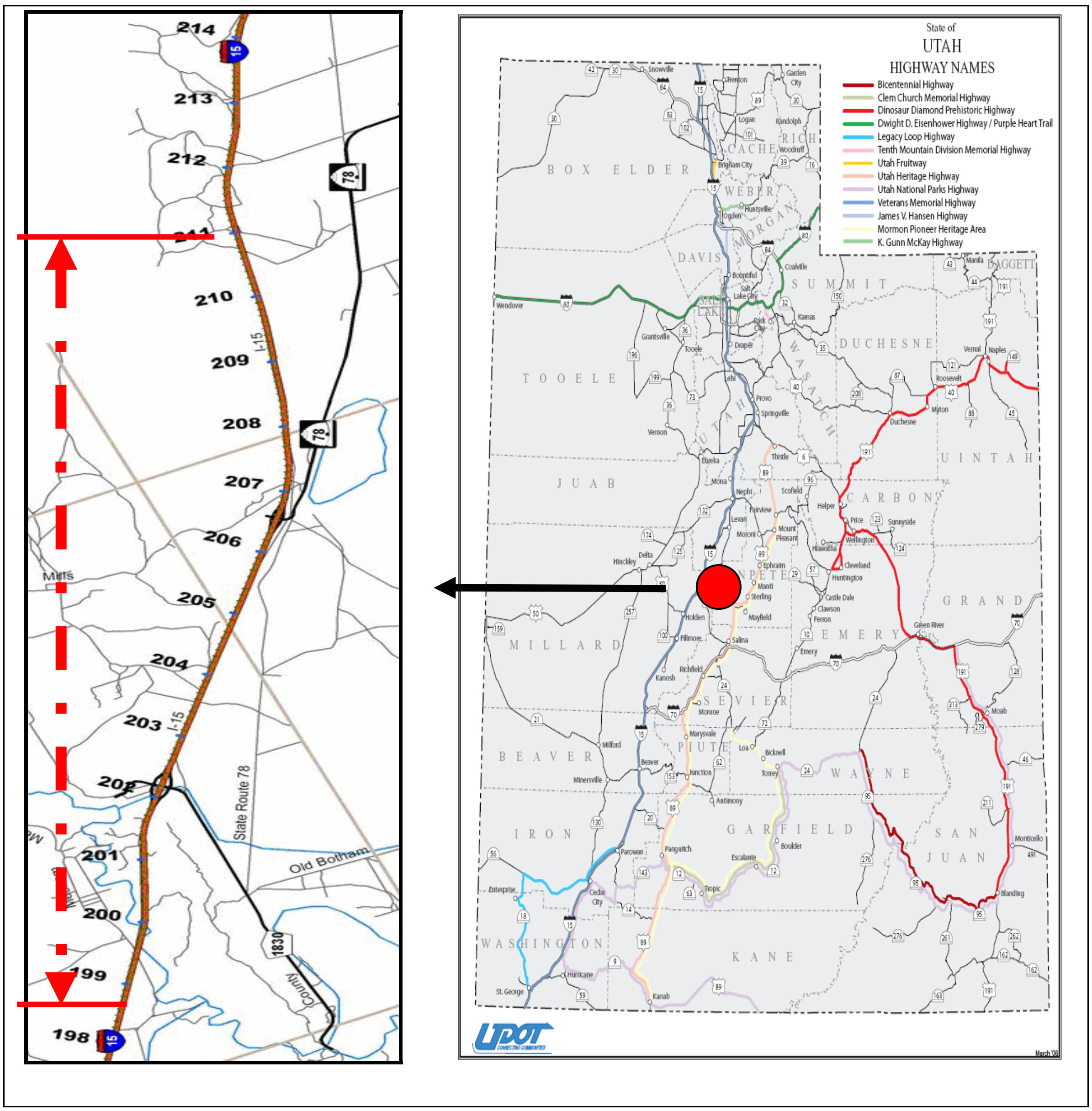
4.1.2 Case II: I-15 From MP 200.07 To MP 211.17, South of Nephi

4.1.2.1 Project Outline

The second project was called "I-15, Sevier River Northward (Reconstruction) Improvements" on Interstate 15, South of Nephi. The work zone spanned from MP 200.07 to MP 211.17, and 11.0 miles in length. The main works of this project included reconstruction and rehabilitation of the roadway.

The total cost of this project was about 19.85 million dollars (UDOT, 2002) and its traffic control cost was $ 1.33 million, which accounted for 7.0% of the total construction cost. The construction began in April, 2002 and finished in June, 2003.

Figure 4-2 shows the location of the case II work zone from MP 200.07 to MP 211.07 on I-15. This work zone was located about 10 miles south of Nephi.



* Source: UDOT Website: http://www.udot.utah.gov (2007)

Figure 4-2 Map of Case II Work Zone: I-15 from MP 200.07 to MP 216.17 MP (I-15 Study Site)

4.1.2.2 Crash Data

Crash data were grouped into three time periods: before, during, and after construction. Crash data for three years from April 1999 to April 2002 were used for the "before" period, crash data for 17.5 months from April 2002 to August 15th of 2003 for the "during" period and crash data for 16.5 months from August 16th of 2003 to December 2004 for the "after" period respectively.

Table 4-2 shows crash rates by severity for the before, during, after analysis period. Crash rates per 100 MVMT (100 Million Vehicle Mile Traveled) decreased as the analysis's period progressed through before and during, and after analysis period. Annual average crash rate and crash rate per 100 MVMT in the before period were 38.33 per year and 80.00 per 100 MVMT, respectively. The annual average crash rate and crash rate per 100 MVMT in the "during" period were 40.80 per year and 79.01 per 100 MVMT, respectively. And, the annual average crash rate and crash rate per 100 MVMT in the "after" period were 79.01 per year and 40.72 per 100 MVMT, respectively. It appears that this construction significantly helped reduce crashes in this stretch. Note that due to the shorter-than three year duration of the construction and the limited availability of after data, the reader should be cautious about the outcome of the analysis. As shown in Table 4-2, the rate of fatal crashes was the highest during the construction (1.60 crashes per 100 MVMT).

Table 4-2 Crash Rates by Severity in the Before, During, and After Construction (I-15 Site)

	Before			During			After		
	Number of Crashes (A)	Annual Average (B)	Crash Rates per 100 MVMT (D)	Number of Crashes (A)	Annual Average (B)	Crash Rates per 100 MVMT (D)	Number of Crashes (A)	Annual Average (B)	Crash Rates per 100 MVMT (D)
No Injury	63.00	21.00	43.83	32.00	25.60	49.58	21.00	14.00	26.72
Possible Injury	22.00	7.33	15.30	6.00	4.80	9.30	5.00	3.33	6.36
Bruises and Abrasion	11.00	3.67	7.65	5.00	4.00	7.75	5.00	3.33	6.36
Broken Bones or Bleeding Blood	17.00	5.67	11.83	6.00	4.80	9.30	1.00	0.67	1.27
Fatal	2.00	0.67	1.39	2.00	1.60	3.10	0.00	0.00	0.00
Total	115.00	38.33	80.00	51.00	40.80	79.01	32.00	21.33	40.72

4.2 Comparison of Two Case Studies

4.2.1 General Description

This section is a summary of the detailed analysis result of the two case studies that are contained in Appendix B. Table 4-3 shows the comparison of the two work zones; one on US-6 and the other on I-15. The construction duration and main works of the two projects are similar, while the lengths of the two work zones are significantly different. The main traffic control device of the work zone on US-6 was barrel (drum) and that of the I-15 site was concrete barrier. The percent share of the traffic control cost to the total construction cost of the US-6 study site, 1.4 % ($150,000), was much smaller than that of the I-15 study site, 6.7 % ($1,330,000). Traffic control cost per mile of the I-15 work zone was three times costlier than the US-6 work zone.

According to the crash rate analysis by severity of two projects, the crash rate of the broken bones or bleeding blood (BBBB) category decreased during construction as compared to before construction. The crash rate of BBBB at the US-6 site fluctuated as time passed, but at the I-15 site it decreased as time passed. Note that the rate of fatal crashes was the highest during construction (bold font). Also, the rate of fatal crashes at the US-6 site increased after construction compared to before construction, while the rate of fatal crashes at the I-15 site decreased to 0.00 crashes per 100 MVMT after construction.

Table 4-3 Comparison of the Two Work Zones

Main Factors		US-6	I-15
Construction Duration		16.5 months	15.0 months
Span of Work Zone		3.72 miles	11.0 miles
Main Works		Rehabilitation& Reconstruction	Rehabilitation& Reconstruction
Main Traffic Control Measure		Barrel (Drums)	Concrete Barrier
Traffic Control Cost ($/mile) (Percent Cost Share, $)		$40,323 (1.4%, $150,000)	$120,909 (6.7%, $1,330,000)
Crash Rate Analysis by Severity (Before → During → After)	BBBB*	29.67→**8.43**→16.72	11.83→**9.30**→1.27
	Fatal	3.71→**8.43**→8.36	1.39→**3.10**→0.00

* BBBB: Broken Bones or Bleeding Blood.

The main difference between these two projects was their traffic control measure. The cost of using barriers for traffic control at the I-15 site was much higher than the cost of using barrels at the US-6 site. It can be said that as far as the data used for this study are concerned the I-15 traffic control measure (concrete Jersey barriers) was better than the US-6 traffic control device (barrels) in terms of crash rate reduction in the BBBB and fatal crash categories.

4.2.2 General Analysis

4.2.2.1 Spatial and Temporal Crash Analyses

Table 4-4 shows the comparison of spatial and temporal crash analysis of the two projects. The sections with highest rates of BBBB or fatal crashes in the two projects were not the work zones themselves but their downstream or upstream sections of the highway, except for the fatal crashes after construction at the US-6 site. After construction, the sections with the largest increase in crash rate for BBBB or fatal crashes in the two projects were upstream or downstream one mile section of the highway from the work zone or inside the work zone. The one-mile sections with highest crash rates in the two projects were both their end sections of the work zone for the three analysis periods. Spring and summer were the most dangerous seasons with highest crash rates observed in the monthly crash rate analysis of the four seasons.

As shown in Table 4-4, the highest number of crashes and most dangerous crashes happened in the transition zones and not in the work zones. Hence, the transition zone of work zones should receive a special attention to maintain traffic safety at work zones. Also, both end sections of the work zones should be of concern for traffic safety because those sections had the highest crash rates. For these two cases, the most dangerous season in the whole year were spring and summer.

Table 4-4 Comparison of Spatial and Temporal Crash Analyses of Work Zones

		US-6	I-15
Section with the Highest Crash Rates (Before → During → After)w	BBBB*	West 5mile→ East 4mile→ West 5mile/East 1mile	North 3mile→ South 2/3mile→ North 2mile
	Fatal	West 4mile→ West 1mile→ Work Zone	North2/3mile→ North 2mile→ South 1/2/4 mile
Section with the Largest Increase in Crash Rate after Construction	BBBB*	East 1mile	North 1mile
	Fatal	Work Zone	South 1/2/4mile
Section with the Highest Crash Rates by Milepost (Before-During-After)		West Ends (Three Periods)	Mid-sections (Before/During construction)→ North End
Month with the Highest Crash Rates		Spring (April 2002, April/May 2003)	Summer (June 2003)

* BBBB: Broken Bones or Bleeding Blood

4.2.2.2 Other Analysis

Table 4-5 shows the comparison of the results of other analyses of the two work zones in terms of crash rates versus factors such as light condition, traffic control measure, alignment, weather condition, surface condition, etc. Most severe crashes and the majority of crashes (90%) happened in ‘daylight’ and ‘dark street or highway not lighted’ conditions.

Crashes with the highest crash rate happened in 'traffic lanes marked' for three construction durations at the work zone except during construction of the I-15 work zone, where the 'construction or work area' had the highest crash rate. But, the traffic controls with the largest increase in crash rate as time progressed were different between the two work zones: the 'no passing lane' control type at the US-6 work zone and the 'traffic signal' control type at the I-15 work zone.

While the highest crash rate happened in the 'curve grade' section of the highway at the US-6 work zone, the high crash rate took place in the 'straight and level' section at the I-15 work zone. Also, the alignment with the largest increase in crash rate as time progressed was different at the two work zones: the 'curve level' section at the US-6 work zone and the 'dip straight' section at the I-15 work zone.

Weather conditions of the two work zones had similar trends for three construction durations. Crashes with the highest crash rate happened in the 'clear' weather condition. Weather condition with the largest increase in crash rate was the 'raining' at the US-6 work zone, while there were no special trends at the I-15 work zone.

Crashes with the highest crash rate took place on the 'dry' pavement surface conditions at the two work zones as time progressed from before construction to after construction. The surface condition with the largest increase in crash rate was the 'wet' condition at the US-6 work zone, while there were no special trends at the I-15 work zone.

The crash types with the highest number of crashes of the two work zones were different between the two work zones: 'MV-wild animal' type at the US-6 work zone and 'MV-MV' type at the I-15 work zone. MV means 'multi-vehicles' crashes.

Table 4-5 Comparison of Other Analyses of the Two Work Zones

		US-6	I-15
Crash Rate Analysis by Severity and Light Condition	BBBB*	Daylight	Daylight, Dark Street or Highway Not Lighted
	Fatal	Dark Street or Highway Not Lighted	Daylight, Dark Street or Highway Not Lighted
The Largest Percentage Share of Light Condition		Dark Street or Highway Not Lighted (56%)	Daylight (72.5%)
Crash Rate Analysis by Analysis Period and Traffic Control (Before → During → After)		Traffic Lanes Marked (for all three periods)	Traffic Lane Marked→Construction or Work Area→Traffic Lane Marked
Traffic Control with the Largest Increase in Crash Rate		No Passing Lanes	Traffic Signal
Crash Rate Analysis by Analysis Period and Alignment (Before → During → After)		Curve Grade for Three Periods	Straight and Level for Three Periods
Alignment with the Largest Increase in Crash Rate		Curve Level	Dip Straight
Crash Rate Analysis by Analysis Period and Weather Condition (Before → During → After)		Snowing → Clear → Clear	Clear for Three Periods
Weather Condition with the Largest Increase in Crash Rate		Raining	-
Crash Rate Analysis by Analysis Period and Surface Condition (Before → During → After)		Dry for all three periods	Dry for Three Periods
Surface Condition with the Largest Increase in Crash Rate		Wet	-
The Highest Crash Type during Construction		MV-Wild Animal	MV-MV

* Broken Bones or Bleeding Blood
- Means that there were no special trends.

The results of the crash rate analyses by light condition ('daylight' or 'dark street or highway not lighted'), traffic control ('traffic lane marked'), weather condition ('clear'), and surface condition ('dry') were similar between the two work zones; however, the results of the crash rate analyses by alignments and crash type produced different results as shown in Table 4-5.

4.2.3 Directional Analysis

Table 4-6 compares the result of directional crash analyses of the two work zones. Results of the crash analyses for traffic control type, alignment, weather condition, surface condition, and crash type of the two directions showed similar trends at the two work zones. On the other hands, other analyses such as crash rate analysis, spatial and temporal crash analysis, crash analyses by severity of the two directions produced different results at the two work zones.

The directional analysis showed that the westbound direction was more dangerous than the eastbound direction at the US-6 work zone, while the northbound direction had similar crash trends as the southbound direction at the I-15 work zone.

Table 4-6 Comparison of Directional Crash Analyses of the Two Work Zones

	US-6 (East-West) (MP 196.79 to MP 200.51)	I-15 (North-South) (MP 200.07 to MP 211.17)
Crash Rates for Analysis of Three Periods	- Westbound had a higher crash rate in all three periods.	- Both directions had similar crash rates in all three periods.
Spatial & Temporal Crash Rate Comparison (Section with the Highest Crash Rates)	- Different by direction and time. - Section of MP 197.0-198.0 had the highest crash rate for the westbound direction. - During and after construction both directions had the highest crash rates in the same section (MP 197.0-198.0) .	- Different by direction and time. - Before construction, both directions had the highest crash rate in the same section (MP206.01-207.80).
Crash Analysis by Severity	- Westbound had severe crashes.	- Both directions were similar. - Before and during construction, southbound had more severe crashes. - After construction, northbound had more severe crashes.
Crash Analysis by Month with the Highest Crash Rates	- Different by direction.	- Month is the same but year is different.
Crash Analysis by Severity and Light Condition	- Different by direction. - Westbound direction had more severe crashes in ‘daylight’ or 'dark street or highway not lighted’.	- Different by direction. - Both direction had similar level of severity; northbound-'daylight', and southbound-'dark street or highway not lighted'.
Crash Analysis by Traffic Control	- Both direction had same (‘traffic lanes marked’) except during construction of the westbound (‘no control present’).	- Same for both direction and time – ‘traffic lanes marked’.
Crash Analysis by Alignment	- Both direction had same (‘curve grade’) except during construction of the eastbound (‘straight and level’).	- Both directions had the same alignment type (‘straight and level’) except before construction of the northbound (‘grade straight’).
Crash Analysis by Weather Condition	- Both directions had the same category (‘snow’ for before construction and ‘clear’ for after construction) except for during construction (‘clear’ for eastbound direction and ‘snowing’ for westbound direction).	- Same by direction and time – ‘clear’.
Crash Analysis by Surface Condition	- Same by direction and time: ‘dry’.	- Same by direction and time: ‘dry’.
Crash Analysis by Crash Type	- ‘MV-Wild Animal’ had the highest number of crashes in both directions.	- MV-MV had the highest number of crashes in both directions.

4.2.4 Crash Analysis by Construction Phase

Table 4-7 compares the results of crash analyses by construction phase of the two work zones. The construction work at the two work zones was divided into three phases. Phase II of the two work zones turned out to have the highest crash rates. Crash analyses by traffic control, surface condition, and crash type by construction phase produced similar results at the two work zones. On the other hand, other analyses by crash rate, spatial and temporal crash rate, crash analysis by severity, alignment, and weather condition of the two work zones produced different results in different directions at the two work zones.

Table 4-7 Comparison of Crash Analyses by Construction Phase of Two Work Zones

		US-6 (East-West) (MP 196.79 to MP 200.51)	I-15 (North-South) (MP 200.07 to MP 211.17)
General Outline			
	# of Phases	3	3
	Phase with the Highest Crash Rate	Phase II	Phase II
	The Longest Phase	Phase I (13 months)	Phase III (7.3 months)
Crash Analysis (The Main Factor with the Highest Crash Rate)			
	Section with the Highest Crash Rate	- Same section for Phase I and Phase III (MP 197.0-198.0). - Phase II (MP 198.0-199.0).	- Same section for Phase II and III (MP 211.01-211.17). - Phase I (207.01-208.00).
	Crash Severity by Phase	Phase I	Phase III
	Crash Rate Analysis by Day of the Week and Phase	- Different by phase.	- Different by phase.
	Crash Rate Analysis by Light Condition and Phase	- Same light condition for Phase I and Phase II ('dark street or highway not lighted'). - Phase III ('daylight').	- Same for all phases ('daylight').
	Crash Rate Analysis by Traffic Control and Phase	- Same for all phases ('traffic lanes marked').	- Same for all phases ('construction or work area').
	Crash Rate Analysis by Alignment and Phase	- Same alignment condition for Phase I and Phase III ('curve grade'). - Phase II ('straight and level').	- Different by phase.
	Crash Rate Analysis by Weather Condition and Phase	- Different by phase.	- Same weather condition for Phase I and II ('clear'). - Phase III ('cloudy').
	Crash Rate Analysis by Surface Condition and Phase	- Same for all phases ('dry').	- Same for all phases ('dry').
	Crash Type	- Same crash type for Phase I and Phase II ('MV-wild animal'). - Phase III ('MV-fixed object').	- Same for all phases ('MV-MV').

According to the analysis by construction phase, Phase I (widening) was the most dangerous among three phases at the US-6 work zone, while Phase III (inside lane construction) was the most dangerous among the three phases at the I-15 work zone. Severe crashes such as 'broken bones or bleeding blood' and 'fatal' crashes happened only in Phase I at the US-6 work zone and the severest crashes happened in Phase III at the I-15 work zone.

4.2.5 Seasonal Analysis

Table 4-8 compares the results of crash analyses for the summer months (June, July, and August) of the two work zones. Crash rates per 100 MVMT for the summer-months at the US-6 work zone increased as time passed, while those at the I-15 work zone decreased. In other words, the traffic safety at the US-6 work zone became worse after construction, but the traffic safety at the I-15 work zone improved. The results of crash rate analyses by severity level were similar between the two work zones.

The spatial and temporal crash rate analyses of the summer months showed that the end sections of the US-6 work zone were more dangerous, while the mid-sections of the I-15 work zone was more dangerous than the other parts of the work zones. The trend in the largest increase in crash rate was the same as the spatial and temporal crash rate analysis. No special similarity in the crash rate analysis was found at the two work zones during the summer months.

Crash rate analysis by light condition for the summer months of the two work zones showed similar results; the highest crash rate happened in the 'daylight' light condition except in the before construction period at the US-6 work zone where 'daylight' was the major light condition. Results of crash rate analysis by traffic control for the summer months at the two work zones were similar to the trend found by the crash rate analysis by light condition for the summer months. On the other hand, the trend of crash occurrence by alignment for the summer-months was significantly different among the two sites as shown in Table 4-8.

Crash rate analyses by weather condition and by surface condition for the summer months at the two work zones were similar to each other: highest crash rates took place in the ‘clear’ weather condition and in the ‘dry’ surface condition, respectively. The summer months had the highest crash rates for the three construction phases.

The crash type analysis showed that the crash types of the highest crash occurrence at the two work zones were different between the two sites: the ‘MV-wild animal’ type was the highest at the US-6 work zone, whereas the ‘ran off roadway-right’ type had the highest number of occurrences at the I-15 work zone.

Table 4-8 Comparison of Crash Analyses for the Summer Months of the Two Work Zones

		US-6 (East-West) (MP 196.79 to MP 200.51)	I-15 (North-South) (MP 200.07 to MP 211.17)
Crash Rate per 100 MVMT for the Summer Months (Before → During → After)		355.8 → 196.96 → 384.09	200.35 → 159.77 → 61.84
Crash Rate Analysis by Severity for the Summer Months (Before → During → After)	BBBB	44.48 → 28.14 → 115.19	33.39 → 21.79 → 0.00
	Fatal	0.00 → 0.00 → 0.00	8.35 → 7.26 → 0.00
Spatial and Temporal Crash Rate Analysis in Work Zone for the Summer Months (Before → During → After)		MP 197.0-198.0 → MP 198.0-199.0 → MP 197.0-198.0	MP 205.0-206.0 → MP 208.0-209.0 → MP 202.0-203.0
Section with the Largest Increase in Crash Rate for the Summer Months		MP 197.0-198.0	MP 203.0-204.0
Crash Rate Analysis by Day of the Week for the Summer Months (Before → During → After)		Mon. → Thu./Fri. → from Tue. to Sun.	Wed. → Fri./Sun. → Wed.
Crash Rate Analysis by Light Condition for the Summer Months (Before → During → After)		‘Dark street or highway not lighted’→ ‘Daylight’→ ‘Daylight’	‘Daylight’→ ‘Daylight’→ ‘Daylight’
Crash Rate Analysis by Traffic Control for the Summer Months (Before → During → After)		Same for three construction periods (‘Traffic lanes marked’)	‘Traffic lane marked’→ ‘Construction or work area’→ ‘Traffic lane marked’
Crash Rate Analysis by Alignment for the Summer Months (Before → During → After)		‘Curve grade’→ ‘Straight and level’→ ‘Grade straight’	‘Straight and level’→ ‘Grade straight’→ ‘Straight and level’
Crash Rate Analysis by Weather Condition for the Summer Months (Before → During → After)		‘Clear’ for three construction periods	‘Clear’ for three construction periods
Crash Rate Analysis by Surface Condition for the Summer Months (Before → During → After)		‘Dry’ for three construction periods	‘Dry’ for three construction periods
Number of Crashes by Crash Type during Construction for the Summer Months		‘MV-wild animal’ (43%)	‘Ran off roadway-right’ (32%)

* BBBB: Broken Bones or Bleeding Blood

Similar to the results of the crash rate analysis for the entire period, light condition ('daylight' or 'dark street or highway not lighted'), traffic control ('traffic lane marked'), weather condition ('clear'), and surface condition ('dry') had the highest crash rates at the two work zones. However, alignment and crash type of the two work zones showed different results as shown in Table 4-8.

4.3 Chapter Summary

As a case study of spatial and temporal crash analysis, two work zones, the construction projects on US-6 and I-15, were chosen. The main difference of the two work zones was traffic control type. In general the analyses of the two work zones showed that even though traffic control cost of the Jersey barrier at the I-15 work zone was much higher than that of using barrels at the US-6 work zone. Although we cannot conclude that concrete barriers are better than drums, we could conclude that the I-15 site was safer than the US-6 site. The I-15 site has much higher cost per mile for traffic control than the US-6 site; the ratio was 1 (US-6) to 3 (I-15), i.e. \$40,323/mi against \$120,909/mi. More spending on traffic control measures at the I-15 work zone was resulted in lower crash rates than at the US-6 site. The traffic safety measures provided at I-15 work zone was better than the traffic safety measures provided at the US-6 work zone.

According to the spatial and temporal crash analyses of the entire data, the transition zone upstream of the work zone was found to be most crash prone and not the work zone itself. Hence, when traffic safety improvement projects are planned, transition sections of work zones should be carefully planned to insure safety in the transition sections. Also, inside the work zones, the end sections of work zones were found to be most crash prone; hence, care must be exercised to improve safety at the end sections of work zones.

Also, the seasonal analysis showed that spring and summer months experienced higher crash rates than the rest of the year. The comparison of crash rates at the two work zones in terms of other factors such as light condition, traffic control measure, alignment, weather condition, surface condition, light condition, traffic control, weather condition, and surface condition showed that the two work zones showed similar trends for these factors. However, the effects of alignment and crash type on the two work zones were significantly different; the highest number of crashes happened in ‘curve grade’ and ‘grade straight’ sections at the US-6 work zone and in ‘straight and level’ and ‘grade straight’ sections at the I-15 work zone.

The directional analysis showed that the westbound direction was more dangerous than the eastbound direction at the US-6 work zone, while the northbound and the southbound directions showed similar trends in crash occurrence at the I-15 work zone.

As for construction phase, Phase I (widening) was found to be the most dangerous among the three phases at the US-6 work zone, while Phase III (inside lane construction) was the most dangerous among the three phases at the I-15 work zone.

Like the results of the crash rate analyses of the entire crash data, highest crash rates for light condition (in ‘daylight’ or ‘dark street or highway not lighted’), traffic control (in ‘traffic lane marked’), weather condition (in ‘clear’), and surface condition (in ‘dry’) showed similar trends at the two work zones; however, trends in crash rates in terms of alignment and crash type were found to be significantly different between the two work zones.

Finally, we concluded that crash occurrence was found to be probabilistic and it scattered over the entire period during construction. Hence, traffic safety enforcements need to be done throughout the entire duration of work.

5 Preparation for Full-Scale Data Mining Analysis

5.1 Methodology

Based on the findings from Chapter 3 Exploratory Data Mining, the ranges of crash data analysis were expanded from the case study analysis periods to a full scale analysis of work zones through the entire state of Utah from 1992 to 2004. Figure 5-1 shows the process of full-scale data mining analysis followed in this study.

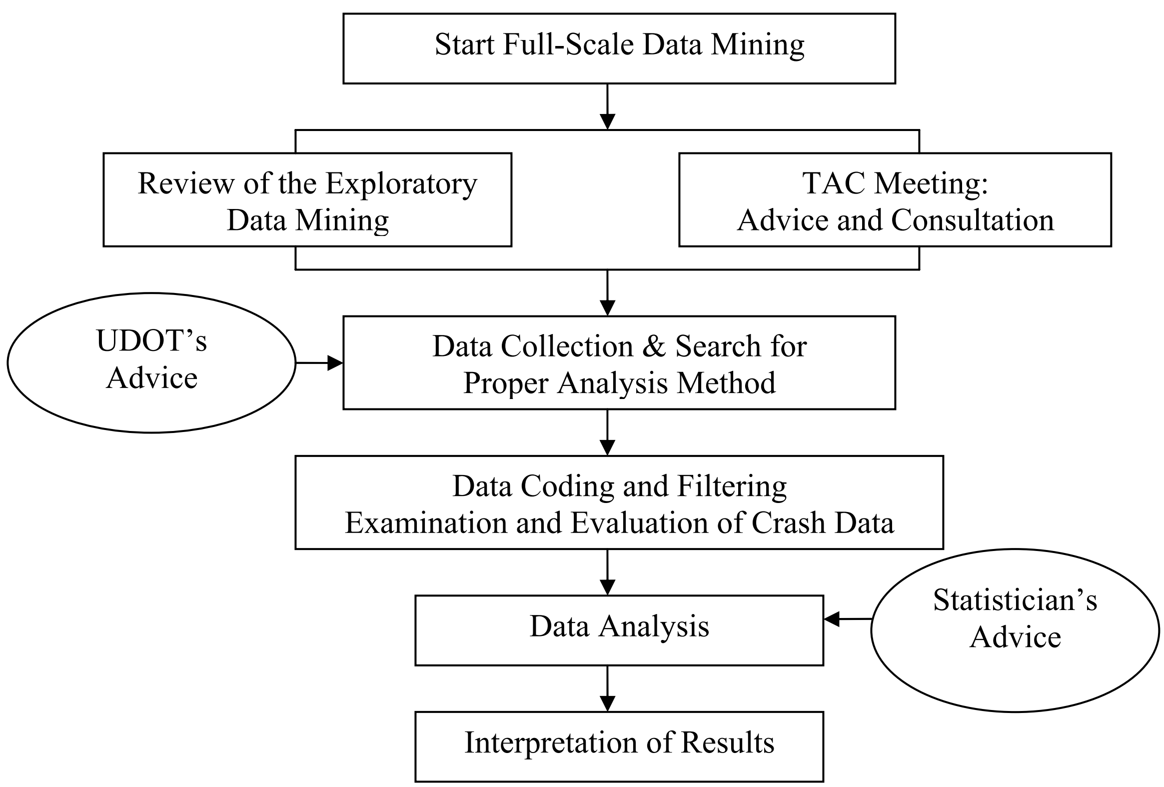


Figure 5-1 Process of Full-Scale Data Mining Analysis

5.2 Data Collection

5.2.1 TAC Meeting

A TAC meeting was held at UDOT on April 20, 2006 in order to review the analysis results of explanatory data mining and discuss how a full-scale data mining should be done.

5.2.2 Data List

The data used in the full-scale data mining were extracted from UDOT's CARS database (2006). The crash data which happened in work zones from 1992 to 2004 in the entire state of Utah were obtained and sorted. The data were divided into categories such as crash, vehicle, people, and carrier information. Table 5-1 shows the main categories for analysis that were requested by the TAC members for the full-scale data mining.

Table 5-1 Factors Considered for Full-Scale Data Mining

UDOT's Request	Factors in Website
- Crash severity levels - Roadway characteristics (straight and level, grade straight, curve level, etc.) - Percent in darkness - Single vehicle/multi-vehicle - Percent trucks - Contributing circumstances: speeding, passing, asleep/fatigued, striking object, etc. - Collision type: head-on, run off the road, rear-end collisions, etc.	○ Main factors - Crash severity - Alignment - Light condition - Crash type - Main contributor - Crash type breakdown ○ Other Factors - Number of Vehicle - Day of the week - Surface condition - Weather condition - Estimated speed - Time

The number of crashes that happened in work zones in the entire state of Utah on its 149 highway routs from year 1992 to 2004 was 21,434. After checking the integrity of the data, 21,126 crash data in 148 routes were analyzed. If the route number, milepost, and date were the same for more than one crash, these crash records were considered identical. Table 5-2 shows the number of work zone related crashes by route.

Table 5-2 Number of Work Zone Related Crashes by Route

Route Number	# of Crashes	Route Number	# of Crashes	Route Number	# of Crashes	Route Number	# of Crashes
6	179	68	604	128	7	212	46
9	208	70	68	130	56	215	874
10	36	71	881	132	25	224	75
12	2	73	62	134	47	225	11
13	18	74	18	138	4	232	26
14	7	75	11	140	2	235	14
15	9106	77	10	142	3	237	4
17	2	79	70	143	2	238	2
18	41	80	795	145	2	239	6
20	15	83	1	146	18	240	4
21	1	84	122	147	7	241	2
23	1	87	4	150	3	248	47
24	8	89	2045	151	212	256	1
26	191	91	350	152	18	257	1
28	6	92	20	154	43	260	1
29	2	93	6	156	23	264	1
30	16	95	2	163	1	265	160
31	16	96	1	164	1	266	162
32	7	97	16	165	59	268	5
34	27	99	1	167	6	269	42
35	11	100	1	171	379	270	26
36	207	101	2	172	91	272	2
37	25	102	2	173	156	273	34
39	54	104	10	180	47	282	55
40	222	105	11	181	26	284	1
41	2	106	8	184	3	288	2
44	1	107	12	186	183	289	2
48	314	108	186	189	433	302	2
50	13	109	6	190	9	491	4
51	2	111	6	191	90	Total	21,434
52	28	112	2	193	125		
53	16	113	14	195	20		
55	3	114	100	197	4		
56	37	115	6	198	72		
58	4	118	2	201	381		
59	6	119	2	202	1		
60	9	120	20	203	105		
62	2	121	14	204	149		
65	3	126	290	209	329		
66	4	127	2	210	5		

5.2.3 Data Processing

Crash data were sorted and coded by following CARS user's manual (2006). In order to achieve the objectives of this study, a full-scale analysis of work zone related crashes in work zones on state-owned highways was conducted. The work zone crash data were extracted from UDOT's crash records from 1992 to 2004. Crash data were sorted and coded by following the user's manual of CARS (UDOT, 2007a), a document prepared by UDOT for users of the CARS database. In order to normalize the sorted crash data and categorize data into the four highway classes, Annual Average Daily Traffic (AADT) for the location where a crash took place was first identified and AADT and highway class were then added to the data extracted from the CARS database. AADTs were obtained from the "Traffic on Utah Highways" section of UDOT's website (UDOT, 2007b).

At the request of UDOT, this study divided state-owned highways into four classes: Rural Interstate highway (RI), Urban Interstate highway (UI), Rural Non-Interstate highway (RNI), and Urban Non-Interstate highway (UNI). Crash severity levels consisted of five levels: No Injury (NI), Possible Injury (PI), Bruises and Abrasion (BA), Broken Bones or Bleeding Blood (BBBB), and Fatal.

5.3 Chapter Summary

Crash data were sorted and summarized by Microsoft Office Excel 2003. Owing to the huge number of data and manipulations associated with the analytical procedures, two special statistical programs, the R program (2006) and the SAS program (2002), were used.

The analyses were carried out with the help of Dr. Denis Eggett and his research assistant, Todd Remund, at the Center for Collaborative Research and Statistical Consulting of Brigham Young University.

The analyses were divided into two major parts, the overall analysis and the factor analysis by severity and highway class. Chapter 6 Results of Full-Scale Data Mining Analysis provides detailed results of the analysis.

6 Results of Full-Scale Data Mining Analysis

Based on the outcome of the data preparation described in chapter 5, work zone crashes that had taken place in the entire state of Utah from 1992 to 2004 were analyzed. Various statistical methods, from basic descriptive statistics to more advanced CATMOD (Categorical Data Modeling) and the TPHREG (Test Proportional Hazards Regression) procedures were used to analyze the relationships between the highway class and the crash severity.

6.1 Overall Analysis

In order to remove the bias caused by the difference in AADT among the crash sites, the normalization of each crash data was made. Basic statistical analyses such as mean, variance, and box plot were performed with the normalized crash rates. To determine how often crashes might happen in particular highway class, the Number of Days to Next Crash (NDTNC) was determined for all crash severity levels.

6.1.1 Summary of Descriptive Statistics

6.1.1.1 Normalization of Crash Data

In order to get the reasonable and scientific results from the full-scale data mining, the raw data collected from UDOT's CARS database (2006) needed to be normalized to incorporate the "exposure" effect. Each crash was multiplied by the weight ratio expressed in million vehicles which was computed as follows;

$$Weight(\omega_t) = (1 \times 10^6)/(365 \times AADT) \quad \textbf{(Equation 6-1)}$$

The reasoning for using this weight ratio is presented here. Each crash took place on a certain route and at a certain mile point on that route. For that mile point on the specific route, AADT was obtained and the value was converted to an average annual traffic, which was obtained by multiplying AADT by 365. Since each observation is representative of one crash, one crash was divided by the annual traffic. Then the quotient was multiplied by one million, so that the weight was given as the number of crashes per million vehicles. All analyses in this chapter were made by using the normalized data (the weight ratio) except for the analyses on crash frequency.

6.1.1.2 Descriptive Statistics

The total number of work zone crash data available for statistical analysis was 21,126 out of 21,434 extracted from the crash database after the integrity of crash data was tested with RI (6%), UI (45%), RNI (15%), and UNI (34%). The mean crash rate of rural highways was higher than that of urban highways, while the standard deviation of crash rates on rural highways was larger than that of urban highways. Table 6-1 shows a summary of descriptive statistics of the four highway classes used in the study.

Table 6-1 Summary of Descriptive Statistics on Crash Rates per Million Vehicles

	RI	UI	RNI	UNI
# of Data (%)	1286 (6%)	9602 (45%)	3077 (15%)	7155 (34%)
Minimum	0.0279	0.0125	0.0388	0.0165
1st Quartile	0.0750	0.0183	0.1087	0.0765
Mean	**0.1863**	**0.0295**	**0.4436**	**0.1389**
Median	0.1573	0.0269	0.2141	0.1018
3rd Quartile	0.2539	0.0341	0.3626	0.1506
Maximum	1.1609	0.5982	11.9119	3.5581
Variance	0.0208	0.0004	0.9232	0.0236
Standard Deviation	**0.1442**	**0.0201**	**0.9608**	**0.1536**
Sum	239.6279	283.3855	1364.8628	994.1629
Standard Error Mean	0.0040	0.0002	0.0173	0.0018
Lower Control Limit Mean	0.1784	0.0291	0.4096	0.1354
Upper Control Limit Mean	0.1942	0.0299	0.4775	0.1425

6.1.2 Estimation of the Number of Days to Next Crash (NDTNC)

6.1.2.1 Outline

Crash frequency data can be used to determine whether a certain section of a work zone is relatively dangerous or safe, or how many crashes happen in a certain section of a work zone. In this analysis, the focus was placed on the effect of highway class on crash occurrence. The number of days to next crash (NDTNC) in work zones was used in this study rather than typical crash rates to compare relative crash occurrences among the four highway classes.

6.1.2.2 Methodology

The value of NDTNC crash was calculated by highway class and by crash severity level. As mentioned in Chapter 5, four highway classes and five crash severity levels were used in the study.

6.1.2.3 Analysis Results

Table 6-2 shows a summary of the descriptive statistics of NDTNC, while Figure 6-1 presents the box plots across highway class and crash severity for all classes. In Table 6-2 "SD" indicates standard deviation and "CI," confidence interval. Confidence intervals were computed at the 95% confidence level.

Because most crashes happened on UI, their mean number of days to next crash (1.67 days) was the shortest among the four highway classes. On the other hand, the mean NDTNC on Rural Non-Interstate highways (3.79 days) had the longest NDTNC, which meant that the crash frequencies on Rural Non-Interstate highways were the lowest.

Also, as shown at the bottom of Table 6-2, the mean numbers of days to next crash in urban areas (1.67 days for UI and 2.09 days for UNI) were shorter than those in rural areas in both interstate and non-interstate highway classes (3.76 days for RI and 3.79 days for RNI), meaning that the crash frequencies on urban highways were higher than those on rural highways. The mean NDTNC on interstate highways (3.76 days) was lower than that of non-interstate highways (3.79 days), meaning more crashes took place on interstate highways, on the average, than on non-interstate highways.

Table 6-2 Summary of Descriptive Statistics on NDTNC

			RI	UI	RNI	UNI	Total
No Injury	**Mean**		**0.73**	**0.56**	**1.20**	**0.73**	**0.72**
	SD		1.19	0.81	5.52	1.76	2.40
	CI	2.5%	0.000	0.000	0.000	0.000	0.000
		97.5%	3.881	2.644	6.626	3.583	3.513
Possible Injury	**Mean**		**1.61**	**1.83**	**2.63**	**2.37**	**2.14**
	SD		2.01	4.42	6.26	4.57	4.72
	CI	2.5%	0.025	0.041	0.000	0.010	0.000
		97.5%	6.075	6.923	16.151	11.010	9.085
Bruises and Abrasion	**Mean**		**5.43**	**5.78**	**6.75**	**6.62**	**6.25**
	SD		6.74	7.99	10.75	12.21	10.20
	CI	2.5%	0.030	0.100	0.042	0.041	0.417
		97.5%	19.750	22.954	29.177	30.620	28.522
BBBB	**Mean**		**9.36**	**7.78**	**14.66**	**10.3**	**10.17**
	SD		8.65	8.64	27.16	15.94	16.41
	CI	2.5%	0.563	0.216	0.202	0.128	0.167
		97.5%	33.388	30.758	107.444	41.423	46.213
Fatal	**Mean**		**121.66**	**60.22**	**177.28**	**102.72**	**100.73**
	SD		158.79	73.88	150.67	94.59	121.35
	CI	2.5%	4.323	3.938	23.824	19.602	3.179
		97.5%	450.409	231.434	423.414	206.641	452.977
Total	**Mean**		**3.76**	**1.67**	**3.79**	**2.09**	
	SD		23.37	7.34	18.90	7.35	
	CI	2.5%	0.000	0.000	0.000	0.000	
		97.5%	17.515	10.709	22.507	13.100	

The longest NDTNC for the four highway classes was aggregated at the Fatal level (100.73 days) and the shortest NDTNC was the No Injury level (0.72), as shown in the far right column of Table 6-2.

The NDTNC at the Fatal level across highway class is wider and higher than the other crash severity levels as shown in Figure 6-1. Also, there are many more outliers in the box plots across crash severity level, shown on the right, than in the plot across highway class, on the left, indicating a large variability among the highway classes.

As shown in the box plot on the left side of Figure 6-1, the NDTNC at the Fatal level across highway class is wider and higher than for the other crash severity levels. In levels other than the Fatal level, there are many outliers, which would affect descriptive statistics such as mean, standard deviation and confidence interval. The NDTNC across crash severity level shown in the box plot on the right side of Figure 6-1 shows the difference in median values between rural and urban highways. Also, there are many more outliers in the box plot across crash severity level than in the plot across highway class, as shown on the left side of Figure 6-1. This clearly indicates that NDTNC varies widely among crash severity levels.

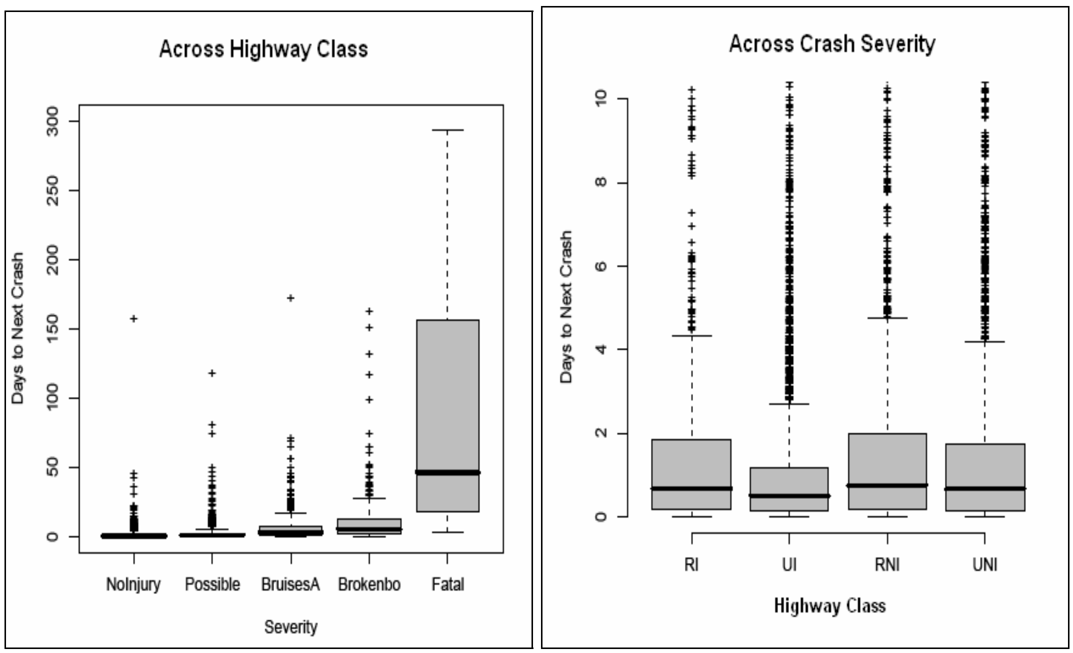


Figure 6-1 Box Plot of NDTNC (All Crashes)

Figure 6-2 shows box plots by highway class. Their descriptive statistics are found in Table 6-2. There is a noticeable difference in the mean NDTNC at the Fatal and the other severity levels, indicating that fatal crashes are rare events. UI had the lowest mean NDTNC in the Fatal level, indicating that UI is the most dangerous among the four highway classes.

Figure 6-3 shows box plots by crash severity level. Their descriptive statistics are found in Table 6-2. Except for the Fatal level, the patterns in NDTNC of the other crash severity levels are similar to each other.

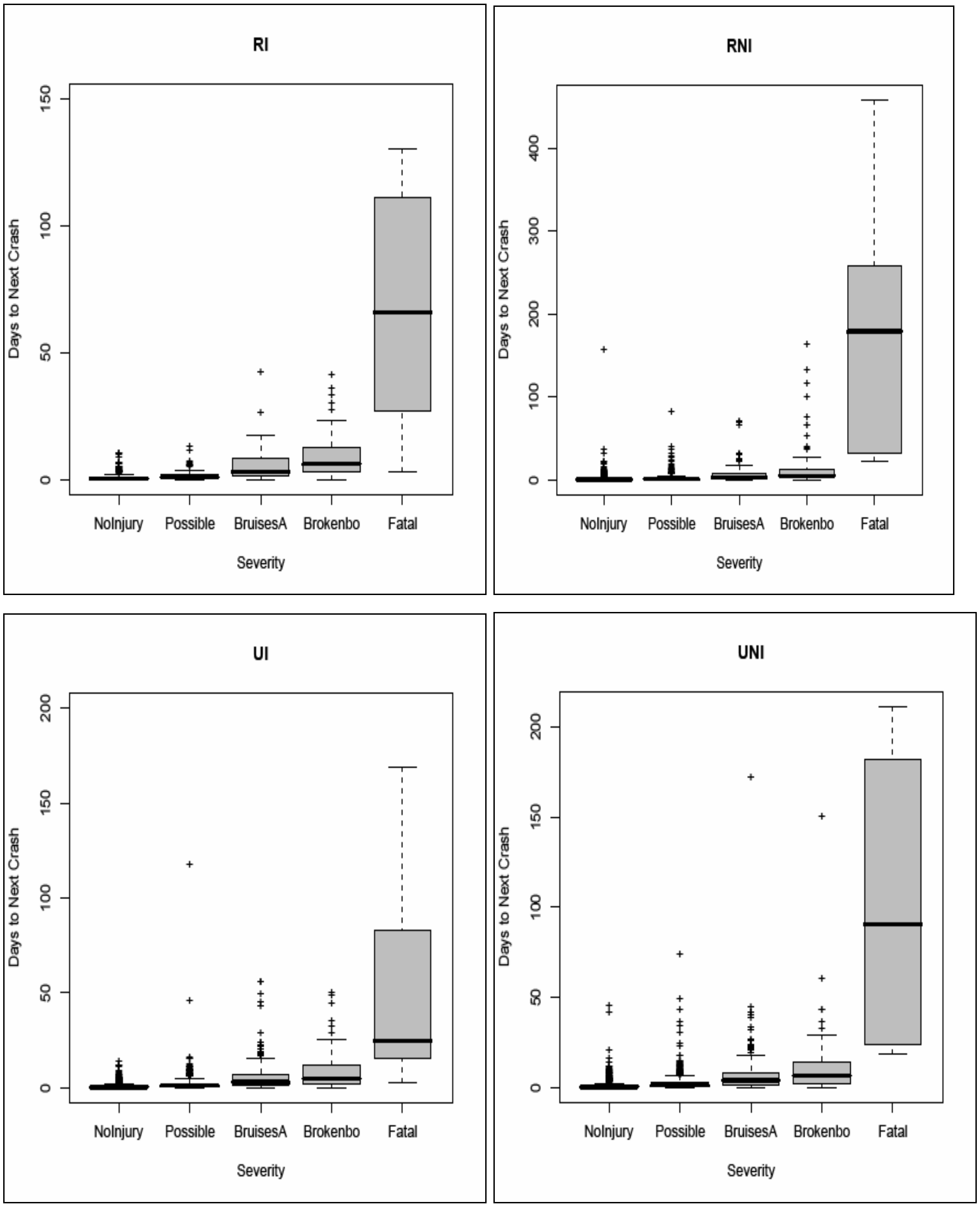


Figure 6-2 Box Plot by Highway Class

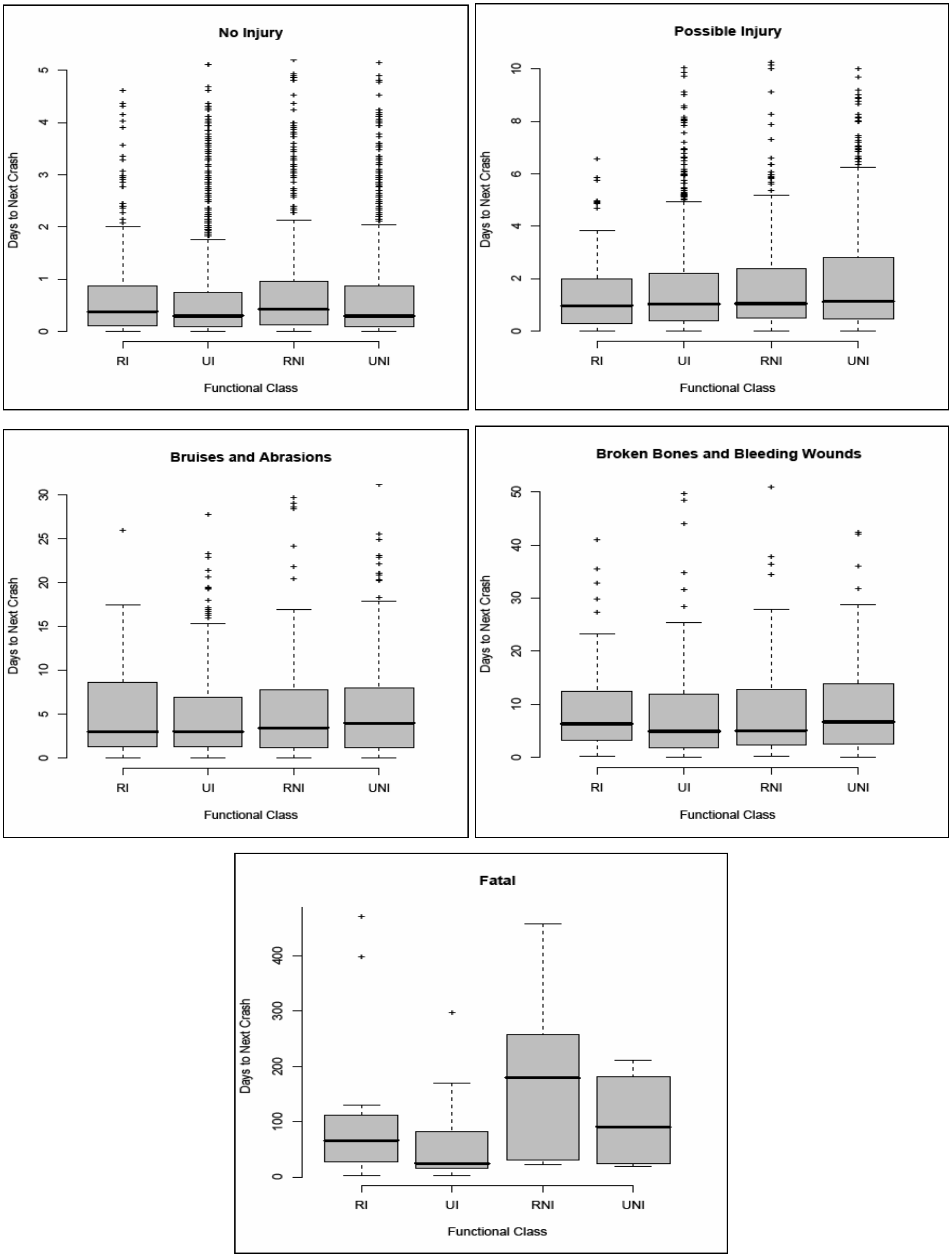


Figure 6-3 Box Plot by Crash Severity Level

6.1.2.4 χ^2 Test

In order to review the independence between highway class and crash severity level, chi-square (χ^2) test was performed. The chi-square test of independence and goodness of fit is a prominent example of non-parametric test. It tests how well an original model (the expected proportions) fits our data (the observed cell counts). Another use of the chi-square test examines whether two categorical variables are independent. Recall that A and B are independent if P (A and B) = P(A)P(B). This relationship is used to determine the expected counts in a table of two variables, and then compare them with the observed counts.

The χ^2 is a measure of actual divergence of the observed and expected frequencies. In sampling studies, it is never expected that there will be a perfect coincidence between actual and observed frequencies and the question is about the degree to which the difference between actual and observed frequencies can be ignored as arising due to fluctuations of sampling. If there is no difference between actual and observed frequencies then $\chi^2 = 0$. If there is a difference, then χ^2 would be more than 0. If the actual value is greater than the critical χ^2 value, the difference is not solely due to sample fluctuation and there are some other reasons. On the other hand, if the calculated χ^2 value is less than the critical χ^2 value, it indicates that the difference may have arisen due to chance fluctuations and can be ignored. Thus, the chi-square test is used to find out if the divergence between theory and fact or between expected and actual frequencies is statistically significant or not. If the calculated value of χ^2 is very small, compared to the critical χ^2 value then expected differences are very little and the fit is good. If the calculated value of χ^2 is very large as compared to the critical χ^2 value then the divergence between the expected and the observed frequencies is very large and the fit is poor.

6.1.2.5 Results

The chi-square test was performed to test independence between highway class and crash severity level. This was done to show that the chi-square test is equivalent to the CATMOD analysis if the data in the contingency table are not sparse, i.e., not too many cells with zeros or less than 5 samples in each cell. If sparse data are presented in the table, the CATMOD analysis is better. The data available for the study were good for the chi-square test, meaning the cell counts are acceptable for the chi-square test. The chi-square test results for highway class and severity level are shown in Figure 6-4 while Figure 6-5 shows the contingency table by the FREQ procedure. As shown in Figure 6-5, each cell contains more than 5 samples, meeting the criterion for a valid chi-square test.

As shown Figure 6-4, the chi-square test result indicated that the overall relationship between functional class and crash severity level statistically existed ($p < 0.0001$) with a few exceptions. Based on the results shown Figure 6-4, the frequency table in Figure 6-5 was created.

Table 6-3 shows a summary of the overall chi-square test. The highest number of crashes happened on Urban Interstate (UI) highway, 9,602 crashes (45.46%). 'No injury' crashes, 13,536 of them (64.09 %) accounted for the most among the five severity levels. The highest number of fatal crashes happened on Rural Interstate (RI) highway (45 fatal crashes).

The CATMOD Procedure

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr>Chi-Square
Highway Class	3	658.07	<.0001
Severity	4	9318.06	<.0001
Highway Class * Severity	12	231.81	<.0001
Likelihood Ratio	0		

Analysis of Maximum Likelihood Estimates					
Parameter		Estimate	Standard Error	Chi-Square	Pr>Chi-Square
Highway Class	1	-0.9243	0.0527	307.42	<.0001
	2	0.8068	0.0370	475.02	<.0001
	3	-0.1806	0.0507	12.67	0.0004
Severity	1	2.1605	0.0300	5171.50	<.0001
	2	1.0726	0.0333	1040.25	<.0001
	3	0.0609	0.0381	2.56	0.1096
	4	-0.3919	0.0407	92.58	<.0001
Highway Class *Severity	11	-0.1637	0.0566	8.37	0.0038
	12	-0.5793	0.0678	72.98	<.0001
	12	-0.2156	0.0796	7.33	0.0068
	14	0.1972	0.0817	5.82	0.0158
	21	0.0871	0.0387	5.07	0.0243
	22	0.1334	0.0422	9.98	0.0016
	23	-0.2156	0.0501	18.49	<.0001
	24	-0.2028	0.0549	13.65	0.0002
	31	-0.1599	0.0530	9.09	0.0026
	32	-0.0715	0.0572	0.02	0.9004
	33	0.0924	0.0650	2.02	0.1552
	34	0.1311	0.0704	3.46	0.0627

Figure 6-4 Result of Likelihood Ratio Chi-Square Test

The FREQ Procedure

Frequen Percent Row Pct Col Pct						

Table of Highway Class by Severity						
Highway Class	Severity					Total
	1	2	3	4	5	
1	877	195	102	98	14	1286
	4.15	0.92	0.48	0.46	0.07	6.09
	68.20	15.16	7.93	7.62	1.09	
	6.48	3.88	6.48	10.85	17.28	
2	6364	2246	576	371	45	9602
	30.13	10.63	2.73	1.76	0.21	45.46
	66.28	23.39	6.00	3.86	0.47	
	47.02	44.68	36.62	41.09	55.56	
3	1852	727	292	193	13	3077
	8.77	3.44	1.38	0.91	0.06	14.57
	60.19	23.63	9.49	6.27	0.42	
	13.68	14.46	18.56	21.37	16.05	
4	4443	1859	603	241	9	7155
	21.04	8.80	2.86	1.14	0.04	33.88
	62.10	25.98	8.43	3.37	0.13	

	32.82	36.98	38.33	26.69	11.11	
total	13536 64.09	5027 23.80	1573 7.45	903 4.28	81 0.38	21120 100.00
Frequency missing =1						

Figure 6-5 Result of Frequency Test

Table 6-3 Summary of Overall Chi-square Test

		RI (1)	UI (2)	RNI (3)	UNI (4)	Total
Crash Severity Level	No Injury (1)	68.2 %	66.28 %	60.19 %	62.1 %	64.09%
	Possible Injury (2)	15.16 %	23.39 %	23.63 %	25.96 %	23.80%
	Bruises and Abrasion (3)	7.93 %	6.00 %	9.49 %	8.43 %	7.45%
	BBBB (4)	7.62 %	3.86 %	6.27 %	3.37 %	4.28%
	Fatal (5)	1.09 %	0.47 %	0.42 %	0.13 %	0.38%
	Sub-total	100.0%	100.0%	100.0%	100.0%	100.0%
Highway Class (Total)		6.09 %	**45.46 %**	14.57 %	33.88 %	100%

6.1.3 Section Summary

After normalizing work zone crash data obtained from UDOT's CARS database (2006), typical descriptive statistical analyses and a chi-square test on NDTNC were performed.

The results of the analysis across crash severity level showed that the mean NDTNC on Urban Interstate highways (1.67 days) was the shortest among the four highway classes while that of the Rural Non-Interstate highways (3.79 days) was the longest. As for crash severity levels, the mean number of days to next 'no injury' crash (0.72) was the shortest among the five crash severity levels while the mean number of days to next fatal crash (100.73) was the longest. The rank of the mean NDTNC was UI (1.67), UNI (2.09), RI (3.76) and RNI (3.79), indicating Urban Interstate highways experience the highest frequency of crashes.

As for highway functional class, the mean NDTNC of urban highways was shorter than that of rural highways. Also, the mean NDTNC on Interstate highways was shorter than that of Non-Interstate highways. The shorter the mean NDTNC of the highways has, the higher the frequencies of crashes and the more dangerous the facilities are. Especially, the NDTNC on Urban Interstate highways in the Fatal severity level is about one half of the mean NDTNC of the Rural Interstate and Rural Non-Interstate highways, as shown in Table 6-2.

The chi-square was performed to test the independence between highway class and crash severity level. This analysis was done to show that the chi-square test result in the same conclusion as the CATMOD analysis if the data in the contingency table (the FREQ table) are not sparse, i.e., not too many cells are with zeros or less than 5 samples. The chi-square test indicated that the overall relationship between highway class and crash severity level was independent with only a few exceptions as shown in Figure 6-4.

According to the results of the frequency test based on the chi-square test, the highest number of crashes happened on Urban Interstate (UI) highways, 9,602 crashes (45.46 %), followed by UNI, RNI, and RI. No Injury crashes, 13,536 crashes (64.09 %), had the highest number of crashes among the five severity levels. The number of fatal crashes on Urban Interstate (UI) highways was the highest among the four highway classes, 55 crashes (1.09%).

Overall, Urban Interstate highways had the highest number of crashes among the four highway classes, 9,602 (45.46%).

6.2 Hazard Ratio Analysis

6.2.1 Methodology

6.2.1.1 Hazard Ratio - TPHREG

In order to compare and evaluate the danger level among the four highway classes by crash severity level, hazard ratio analysis using TPHREG (Test Proportional Hazards Regression) was performed. The TPHREG analysis adds the class statement to the PHREG procedure. Covariates, main effects, interactions and nested effects can be specified as model effects; this feature is similar to the GLM (General Linear Model) procedure (SAS Institute, 2002).

The SAS survival analysis procedure, PHREG, is useful when the analysis does not require, the probability distribution of each event. Survival curves for given sets of covariates will also be obtained through PHREG. The magnitude of the hazard rate can be estimated from the survival curve. Therefore, a complete set of comparable hazard rates will be determined through PHREG, which was combined with the hazard ratio.

Hazard ratios were calculated by fitting the data into Cox Proportional Hazard Regression models using TPHREG. That is to say, hazard ratios, or the number of events expected per individual class per unit time, may be the most useful way to compare different highway classes. The inverse of the hazard ratio indicates the expected duration in the state under consideration.

6.2.1.2 Cox Regression

The proportional hazard model is defined as (SAS Institute, 2002),

$$\lambda_i(t) = \lambda_0(t) e^{\chi_i^T \beta} \qquad \textbf{(Equation 6-2)}$$

where the function $\lambda_0(t)$ is called the baseline hazard. The vector χ_i is the vector of factor level variables defining what risk factors are measured on individual class i. In our case this vector is a vector of zeros and a one. Each element of the vector represents a place holder to define if a crash occurred in any one of the four highway classes. The parameter vector β is expressed in terms of the mean weight ratio for each highway class, μ_i, as follows:

$$\beta = \begin{pmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{pmatrix} = \begin{pmatrix} \mu_4 \\ \mu_1 - \mu_4 \\ \mu_2 - \mu_4 \\ \mu_3 - \mu_4 \end{pmatrix} \qquad \textbf{(Equation 6-3)}$$

The baseline hazard is where β_0 intercepts. This intercept (β_0) is chosen as the last class (μ_4), that is the parameters for the fourth highway class (UNI: Urban Non-Interstate highway). The rest of the parameters (β_1 through β_3) represents difference between other highway classes (μ_1, μ_2, and μ_3) and the reference class (μ_4).

The mathematics of the model requires this type of parameterization in order to estimate the parameters. Also, in the estimation process, the baseline hazard is thrown away and is not available to estimate the means of the different groups; hence, this model is useful only for finding relative risk between different highway classes.

To find the solution to this model we need to estimate the parameters in the model, namely the β's. To do this, we use the Cox Partial Likelihood analysis. The usefulness of the model is found in the calculation of the relation, which is the calculation of the ratio of two hypothetical crash profiles X and X*

$$\frac{h(t|X)}{h(t|X^*)} = \frac{e^{X\beta}}{e^{X^*\beta}} = e^{(X-X^*)\beta} \quad \textbf{(Equation 6-4)}$$

The way the parameters are set up in equation 6-2, is identical to the quantity on the right hand side of equation 6-3. This gives the relative risk of a crash in one highway class compared to another highway class. It is seen in the ratio that the baseline hazard cancels out and doesn't matter in estimating the hazard ratios or relative risks.

The reason for choosing this model in this study is to find a relation between the highway classes in terms of crash occurrence.

6.2.1.3 Interpretation of Hazard Ratio

First, the parameterization of the model in SAS is achieved. The following are the parameters that are fit using the SAS model based on the transform of equation 6-3.

$$\begin{pmatrix} \beta_0 = \mu_4 \\ \beta_1 = \mu_1 - \mu_4 \\ \beta_2 = \mu_2 - \mu_4 \\ \beta_3 = \mu_3 - \mu_4 \end{pmatrix} \qquad \textbf{(Equation 6-5)}$$

The intercept, β_0, is not estimated in the model, and indeed is not important in estimation and inference. What is important are the hazard ratios and making inference on them. These values are put through the exponentiation and the hazard ratios are computed by the following;

$$e^{\beta_1} = e^{\mu_1 - \mu_4} = \frac{e^{\mu_1}}{e^{\mu_4}} \qquad \textbf{(Equation 6-6)}$$

The ratio above is a measure of the relative risk of a crash in this analysis. As shown Figure 6-6, the table labeled Contrast Test Results contains the tests of the contrasts that were performed for the BBBB severity level. Inside this table, the test called 'All levels the same' is shown, which tests to see if at least one of the means of highway classes is different from the rest. The test came out significant with a p-value of <.0001. The rest of the tests of the individual comparisons were also significant, with a 5% significant level.

This TPHREG procedure produces an output shown in Figure 6-7, the output table of the Contrast Row Estimation and Testing Results section of the output. The Estimate column in Figure 6-7 shows the hazard ratios for each of the different contrasts. Let's look at the one labeled RI vs. UI. The ratio is 0.0675 which means that in the crash severity level 'Broken Bones or Bleeding Blood', highway class RI is 0.0675 times more likely to have a crash in this severity level than highway class UI. Maybe a more suitable way of putting this comparison is to invert the value and say, highway class UI is 1/0.0675 = 14.81 times more likely to have ‘broken bones or bleeding bloods’ crash type than highway class RI. Figure 6-6 shows that this hazard ratio to be significant, that is, the p-value for the RI vs. UI contrast is $p < 0.0001$.

Contrast Test Results			
Contrast	DF	Wald Chi-Square	Pr > ChiSq
All levels the same	3	493.4383	<.0001
RI vs. UI	1	274.0438	<.0001
RI vs. RNI	1	12.4610	0.0004
RI vs. UNI	1	19.9596	<.0001
UI vs. RNI	1	417.4954	<.0001
UI vs. UNI	1	221.8860	<.0001
RNI vs. UNI	1	72.4661	<.0001

Figure 6-6 Analysis Procedure of Hazard Ratio using TPHREG

The TPHREG Procedure

sev=Brokenbo

Contrast Rows Estimation and Testing Results									
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits		Wald Chi-Square	Pr > ChiSq
RI vs. UI	EXP	1	0.0675	0.0110	0.05	0.0491	0.0929	274.0438	<.0001
RI vs. RNI	EXP	1	1.8191	0.3083	0.05	1.3049	2.5359	12.4610	0.0004
RI vs. UNI	EXP	1	0.5041	0.0773	0.05	0.3733	0.6808	19.9596	<.0001
UI vs. RNI	EXP	1	26.9312	4.3407	0.05	19.6364	36.9359	417.4954	<.0001
UI vs. UNI	EXP	1	7.4632	1.0071	0.05	5.7288	9.7226	221.8860	<.0001
RNI vs. UNI	EXP	1	0.2771	0.0418	0.05	0.2062	0.3724	72.4661	<.0001

Figure 6-7 Output Table Named Contrast Row Estimation and Testing Results

6.2.2 Analysis Results

6.2.2.1 Statistical Significance (p-Values)

In order to ensure that the results were statistically significant, p-values were evaluated. The 5% significance level ($\alpha = 0.05$) was used to test the hypothesis. If the p-values of all highway classes and comparisons of two highway classes were less than 0.05, the results were statistically significant, meaning that at least one of the means of highway class was statistically different from the rest at the 5% significant level and among them needed to pinpoint which pair would be statistically different.

Table 6-4 shows a summary of the Contrast Row Estimation and Testing Results section of SAS's TPHREG output. All p-values were less than <.005, meaning that all results were statistically significant at the 5% significance level. This allowed a comparison of the hazard ratio among all highway classes by crash severity level.

In preparing Table 6-4, the all contrasts such as RI vs. UI, RI vs. RNI, and UI vs. RNI, were removed in order to calculate β_i mentioned in the Cox Regression section and only the contrast against highway class UNI were listed. Table 6-4 also shows the other pertinent statistics including estimates (Hazard Ratios), standard errors, confidence limits, chi-square values, and p-values. The "estimates" are the hazard ratios between a highway class against highway class UNI.

Table 6-4 Summary of 'Contrast Row Estimation and Testing Results'

No Injury								
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits	Wald Chi-square	Pr>ChiSq
RI vs. UNI	EXP	1	0.6448	0.0319	0.05	0.5852-0.7104	78.7506	<.0001
UI vs. UNI	EXP	1	11.5372	0.4087	0.05	10.7634-12.3667	4766.0624	<.0001
RNI vs. UNI	EXP	1	0.3813	0.0159	0.05	0.3513-0.4139	531.2787	<.0001
Possible Injury								
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits	Wald Chi-square	Pr>ChiSq
RI vs. UNI	EXP	1	0.6529	0.0684	0.05	0.5317-0.8017	16.5579	<.0001
UI vs. UNI	EXP	1	12.4747	0.7693	0.05	11.0544-14.0774	1674.6896	<.0001

RNI vs. UNI	EXP	1	0.4868	0.0334	0.05	0.4255-0.5569	109.8496	<.0001
Bruises or Abrasion								
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits	Wald Chi-square	Pr>ChiSq
RI vs. UNI	EXP	1	0.5153	0.07	0.05	0.3948-0.6726	23.7899	<.0001
UI vs. UNI	EXP	1	23.9184	3.3283	0.05	18.2089-31.4181	520.4806	<.0001
RNI vs. UNI	EXP	1	0.3597	0.0399	0.05	0.2895-0.4470	85.1749	<.0001
BBBB								
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits	Wald Chi-square	Pr>ChiSq
RI vs. UNI	EXP	1	0.5041	0.0773	0.05	0.3733-0.6808	19.9596	<.0001
UI vs. UNI	EXP	1	7.4632	1.0071	0.05	5.7288-9.7226	221.886	<.0001
RNI vs. UNI	EXP	1	0.2771	0.0418	0.05	0.2062-0.3724	72.4661	<.0001
Fatal								
Contrast	Type	Row	Estimate	Standard Error	Alpha	Confidence Limits	Wald Chi-square	Pr>ChiSq
RI vs. UNI	EXP	1	0.1816	0.1222	0.05	0.0485-0.6794	6.4215	0.0113
UI vs. UNI	EXP	1	10.9604	7.6304	0.05	2.8005-42.8958	11.8281	0.0006
RNI vs. UNI	EXP	1	0.0658	0.0522	0.05	0.0139-0.3116	11.7585	0.0006

6.2.2.2 Hazard Ratio by Crash Severity

As mentioned in 6.2.1.3 Interpretation of Hazard Ratio of this chapter, The Estimates in Table 6-4 are the hazard ratios for each of the different contrasts. Equation 6-5 shows that the rest of these parameters represent difference between the highway classes and the reference class (μ_4), which was chosen as the UNI, Urban Non-Interstate highway.

Table 6-5 shows the comparison of hazard ratios of the highway classes by crash severity level. Note that highway class UI was found to be the most dangerous among the four highway classes in all crash severity levels (see the right most column of Table 6-5). Also, the ranks of the danger level of the four highway classes were the same in all crash severity levels as shown in the table. Note that the hazard ratio of highway class UI in the Bruise and Abrasion crash severity level was much higher than that of the other crash severity levels (UI vs. UNI, estimate 23.92).

As the result of the hazard ratio analysis, hazard ratios between the contrasted highway classes and the reference highway class, UNI, were obtained, such as RI:UNI = 0.18:1.00, UI:UNI=10.96:1.00, RNI:UNI= 0.07:1.00 for the Fatal crash severity level. Using this sequential hazard ratio, highway class ranking in terms of relative hazard ratio such as RI:UI:RNI:UNI = 0.18:10.96:0.07:1.00 (UI > UNI > RI > RNI) was computed for each crash severity level. This order indicates that UI is the most dangerous highway class in the Fatal crash severity level. In summary, the Urban Interstate highway class was found to be the most dangerous among the four highway class as shown in Table 6-5 and requires special attention to improve traffic safety levels.

Table 6-5 Hazard Ratio Analysis Result of the Entire Severity Levels

	Hazard ratio				Danger Comparison	
	Comparison Based on Reference FC			Entire Comparison	Road Functional Class	Highest
	RI vs. UNI	UI Vs. UNI	RNI vs. UNI	RI:UI:RNI:UNI		
No Injury	0.64	11.54	0.38	0.64:11:54:0.38:1.00	UI>UNI>RI>RNI	UI
Possible Injury	0.65	12.47	0.49	0.65:12.47:0.49:1.00	UI>UNI>RI>RNI	UI
Bruises and Abrasion	0.52	23.92	0.36	0.52:23:92:0.36:1.00	UI>UNI>RI>RNI	UI
BBBB	0.50	7.46	0.28	0.54:7.46:0.28:1.00	UI>UNI>RI>RNI	UI
Fatal	0.18	10.96	0.07	0.18:10.96:0.07:1.00	UI>UNI>RI>RNI	UI

6.2.3 Section Summary

In order to compare and evaluate the danger level among the four highway classes by crash severity, the hazard ratio analysis using the TPHREG (Test Proportional Hazards Regression) procedure of SAS was applied. The TPHREG procedure was used to determine comparative risk level of the four highway classes.

In the hazard ratio analysis, hazard ratios between the contrasted highway class and the reference highway, UNI, were obtained such as RI:UNI=0.18:1.00, UI:UNI= 10.96:1.00, and RNI:UNI= 0.07:1.00 in the Fatal crash severity level, for example. Using this sequential hazard ratio, highway class ranking in terms of relative hazard ratio like RI:UI:RNI:UNI = 0.18:10.96:0.07:1.00 (UI > UNI > RI > RNI) was determined. This order indicates that UI (Urban Interstate highway class) is the most dangerous highway class in the Fatal crash severity level.

In summary, the Urban Interstate highway class was found to be the most dangerous highway class among the four highway classes at all crash severity levels as shown in Table 6-5.

6.3 Results of Other Factor Analysis

6.3.1 Methodology - CATMOD Procedure or Categorical Model

In this analysis, data were represented in a contingency table, that is, a table of counts of highway class and crash severity combination cells. After having evaluated the relative risk between different highway classes, as discussed in 6.2 Hazard Ratio Analysis of this chapter, the next step is to find what might be the reason for these differences, or to find out why one highway class is more dangerous than the others. In order to perform such analyses, data are grouped into different highway groups by severity level. For example, all the No Injury crash data are lumped into a table, Possible Injury crash data lumped into another, and so on.

After grouping the data, the different risk factors are evaluated and contributors are identified. For example, a question may be asked – "do the highway characteristics affect what the risk is regarding highway class?" Cox regression was used to answer such questions. The crash data were standardized for highway class and crash severity level, but the risk factors were defined on different segments of highway, such as straight segments and curves in the highway. Note that there were no normalizing values to standardize these factors. Categorical methods were used to account for these factors.

The proportion of crashes that represents highway class *i* and highway characteristic *j* is defined as π_{ij}. The question is, "Does highway class have an association to highway characteristic?" If $\pi_{ij} = \pi_{i.}\pi_{.j}$ is proven, it is concluded that the two factors are independent of one another. The subscript (*i.*) or (*.j*) tells that these are marginal proportions: (*i.*) is a row proportion and (*.j*) is a column proportion. $\pi_{i.}$ or any proportions can be estimated by taking the number of observations that are in factor *i* (n_i) and dividing that by the total number of observations (*n*). So,

$$\pi_{ij} = \frac{n_{i.}}{n}\frac{n_{.j}}{n} = \alpha_i \beta_j \qquad \textbf{(Equation 6-7)}$$

Hence,

$$\mu_{ij} = n\pi_{ij} = n\alpha_i\beta_j = \mu\alpha_i\beta_j \qquad \textbf{(Equation 6-8)}$$

where μ_{ij} is the mean of the value, that is, the expected number of crashes the cell (*i, j*) in the contingency table. A log-linear model is used to create a linear model to find the value of μ_{ij} The log-linear model of equation 6-8 becomes:

$$\log\mu_{ij} = \log\mu + \log\alpha_i + \log\beta_j = \lambda + \lambda_i^X + \lambda_j^Y \qquad \textbf{(Equation 6-9)}$$

or

$$\log\mu_{ij} = \log\mu + \log\pi_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_{ij}^{XY} \qquad \textbf{(Equation 6-10)}$$

If the reduced model (equation 6-9) doesn't fit as well as the saturated model (equation 6-10), then there is an association between the two factors *X* and *Y*. This process determines if the interaction is negligible or not, based on a likelihood based hypothesis test. In CATMOD, if we fit the reduced model without the interaction in it, the output will include an overall model test that tests the information explained by the reduced model against the information explained by the saturated model and tells whether they explain the same amount of information. And if the reduced model is no different than the saturated model in explaining information portrayed by the data; then, there is no association between the two factors *X* and *Y*, and the variables *X* and *Y* can be analyzed separately.

6.3.2 CATMOD Procedure

There was evidence that the data described in the contingency tables could be modeled using the chi-square distribution; hence, no chi-square test was used for testing independence. It was implicitly decided by realizing that the contingency tables were sparse, i.e., many cells had no data or counted less than 5 in the contingency cells. Therefore, the CATMOD procedure in SAS was used to test for independence.

As the first step of CATMOD procedure, tests for the two way tables were performed and the overall test for three-way independence was done to get the desired results. If there was three-way independence, it could be said that if any one of the values for the three variables changes, it affects the others. Then, when the two way tables are examined, the conditional independence of the third variable "severity level" is tested.

Note that the tests used in the CATMOD procedure use a chi-square test. The chi-square test was used simply because the likelihood ratio test uses a statistic that is distributed with a chi-square distribution. This use of chi-square test is different from the chi-square test used for a contingency table test. The following subsections discuss the steps of CATMOD procedure using crash severity level 1, No Injury as an example.

6.3.2.1 Step1: Data Summary

Figure 6-8 shows the CATMOD analysis procedure, step 1: data summary for the alignment factor by highway class for severity level, No Injury. As the first step of CATMOD analysis, the information on data is summarized. The main information included in these data were the response of analysis items, weight variable, data set, frequency missing, response levels, populations, total frequency, and the number of observations. In Figure 6-8, the func_class means "highway class" and the r_c means "road characteristics", i.e., alignment type.

The CATMOD Procedure

sev=1

Data Summary			
Response	func_class*r_c	**Response Levels**	28
Weight Variable	None	**Populations**	1
Data Set	TRAFF	**Total Frequency**	13513
Frequency Missing	24	**Observations**	13513

Population Profiles	
Sample	**Sample Size**
1	13513

Figure 6-8 CATMOD Analysis Procedure, Step1: Data Summary

6.3.2.2 Step 2: Response Profile

Figure 6-9 shows the CATMOD analysis procedure, step 2: response profile. The second step of CATMOD analysis shows the responses of the CATMOD analysis. The number of analytical item in response profiles was determined by the multiplication of the number of severity level (5 types - 1 type) and the number of the other factor, alignment in this example (8 types – 1 type). Therefore, the number of response profile in the alignment by highway class and crash severity level is 28 (4×7). Figure 6-9 shows the response profiles of the alignment by highway class and crash severity level 1, No Injury.

The CATMOD Procedure

sev=1

Response Profiles		
Response	**func_class**	**r_c**
1	1	CirveHil
2	1	CurveGra
3	1	CurveLev
4	1	Dip
5	1	GradeStr
6	1	Hillcres
7	1	Straight
8	2	CirveHil
9	2	CurveGra
10	2	CurveLev
11	2	Dip
12	2	GradeStr
13	2	Hillcres
14	2	Straight
15	3	CirveHil
16	3	CurveGra
17	3	CurveLev
18	3	Dip
19	3	GradeStr
20	3	Hillcres
21	3	Straight
22	4	CirveHil
23	4	CurveGra
24	4	CurveLev
25	4	Dip
26	4	GradeStr
27	4	Hillcres
28	4	Straight

Maximum Likelihood Analysis
Maximum likelihood computations converged.

Figure 6-9 CATMOD Analysis Procedure, Step2: Response Profile

6.3.2.3 *Step3: Maximum Likelihood Estimates*

Figure 6-10 shows the CATMOD analysis procedure, step 3: the analysis result of maximum likelihood estimates. As the third step of CATMOD analysis, this step shows the intermediate analysis result of CATMOD. The results of maximum likelihood estimates are separately given for the overall parameters and for each parameter level. Figure 6-10 shows the maximum likelihood estimates of the alignment factor by highway class for crash severity level 1, No Injury.

Figure 6-10 shows Maximum Likelihood Analysis of Variance at the test labeled 'Likelihood Ratio', which has the exact same values as previous class. So, the CATMOD approach was used from here on to test independence. This analysis was done by severity level as shown in the top part of Figure 6-10. If the test p-value is less than 0.05, it is inferred that there was evidence to reject the null hypothesis. The null hypothesis was that there was no association between highway class and the variable you are comparing it against highway condition while controlling for the severity level. When the p-value is less than 0.05, it was inferred that there is dependence between highway class and the variable. In such case, it is concluded that when a crash occurs in a certain highway class they may tend to be found in a certain level of the other variable.

In the sample output shown in Figure 6-10, the p-value are all <0.001 indicating that the null hypotheses was rejected. The interaction of the two primary factors were significant and it can be said that there was the dependence between highway class (func_class) and highway condition (r_c) when crash severity level 1, No Injury crashes, is considered.

The CATMOD Procedure

sev=1

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	4506.37	<.0001
r_c	6	16485.22	<.0001
Likelihood Ratio	18	936.49	<.0001

Analysis of Maximum Likelihood Estimates					
Parameter		**Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**
func_class	**1**	-1.0900	0.0265	1692.27	<.0001
	2	0.8952	0.0144	3852.21	<.0001
	3	-0.3412	0.0200	290.85	<.0001
r_c	**CirveHil**	-1.9327	0.0929	433.29	<.0001
	CurveGra	0.1974	0.0394	25.15	<.0001
	CurveLev	0.3563	0.0375	90.10	<.0001
	Dip	-2.0269	0.0970	436.42	<.0001
	GradeStr	1.0841	0.0314	1189.30	<.0001
	Hillcres	-0.4150	0.0485	73.14	<.0001

Figure 6-10 CATMOD Analysis Procedure, Step3: Maximum Likelihood Estimates

6.3.2.4 Step 4: Final Result

Figure 6-11 shows the CATMOD analysis procedure, step 4: final result. As the final step of CATMOD analysis, this step shows the final analysis result of CATMOD. Keep in mind that the value 1×10^6 / (AADT×365) is used as a weight to normalize crash occurrence. It was not certain AADT can completely normalize the data, but this normalization was the best approach available with the extracted crash data.

As shown Figure 6-11, most of the crashes of the No Injury severity level took place in ‘straight’ alignment section of all functional classes (70.24%), followed by the ‘grade-straight’ alignment (13.45%) and the ‘curve-level’ alignment (6.50%).

The FREQ Procedure

Frequency Percent Row Pct Col Pct

Table 1 of func_class by r_c								
Controlling for sev=1								
	r_c							
func_class	CirveHil	CurveGra	CurveLev	Dip	GradeStr	Hillcres	Straight	Total
1	14 0.10 1.60 15.73	123 0.91 14.09 16.42	62 0.46 7.10 7.06	5 0.04 0.57 6.17	222 1.64 25.43 12.21	30 0.22 3.44 7.39	417 3.09 47.77 4.39	873 6.46
2	44 0.33 0.69 49.44	389 2.88 6.12 51.94	626 4.63 9.85 71.30	50 0.37 0.79 61.73	723 5.35 11.38 39.77	205 1.52 3.23 50.49	4319 31.96 67.95 45.50	6356 47.04
3	17 0.13 0.92 19.10	155 1.15 8.40 20.69	89 0.66 4.82 10.14	8 0.06 0.43 9.88	403 2.98 21.83 22.17	46 0.34 2.49 11.33	1128 8.35 61.11 11.88	1846 13.66
4	14 0.10 0.32 15.73	82 0.61 1.85 10.95	101 0.75 2.28 11.50	18 0.13 0.41 22.22	470 3.48 10.59 25.85	125 0.93 2.82 30.79	3628 26.85 81.75 38.22	4438 32.84
Total	89 0.66	749 5.54	878 6.50	81 0.60	1818 13.45	406 3.00	9492 70.24	13513 100.00
Frequency Missing = 24								

Figure 6-11 CATMOD Analysis Procedure, Step 4: Final Result

6.3.3 Summary of CATMOD Analysis

6.3.3.1 Overall Analysis – Result of Maximum Likelihood Estimates

Figure 6-12 shows the results of analysis of maximum likelihood estimates for highway class and crash severity level. The most important thing in this analysis is to review the p-value which checks whether the maximum likelihood estimates are statistically significant or not.

The CATMOD Procedure

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
func_class	3	685.07	<.0001
sev	4	9318.06	<.0001
func_class*sev	12	231.81	<.0001
Likelihood Ratio	0	.	.

Analysis of Maximum Likelihood Estimates					
Parameter		Estimate	Standard Error	Chi-Square	Pr > ChiSq
func_class	1	-0.9243	0.0527	307.42	<.0001
	2	0.8068	0.0370	475.02	<.0001
	3	-0.1806	0.0507	12.67	0.0004
sev	1	2.1605	0.0300	5171.50	<.0001
	2	1.0726	0.0333	1040.25	<.0001
	3	0.0609	0.0381	2.56	0.1096
	4	-0.3919	0.0407	92.58	<.0001
func_class*sev	1 1	-0.1637	0.0566	8.37	0.0038
	1 2	-0.5793	0.0678	72.98	<.0001
	1 3	-0.2156	0.0796	7.33	0.0068
	1 4	0.1972	0.0817	5.82	0.0158
	2 1	0.0871	0.0387	5.07	0.0243
	2 2	0.1334	0.0422	9.98	0.0016
	2 3	-0.2156	0.0501	18.49	<.0001
	2 4	-0.2028	0.0549	13.65	0.0002
	3 1	-0.1599	0.0530	9.09	0.0026
	3 2	-0.00715	0.0572	0.02	0.9004
	3 3	0.0924	0.0650	2.02	0.1552
	3 4	0.1311	0.0704	3.46	0.0627

Figure 6-12 Overall Analysis Result of Maximum Likelihood Estimates

As we discussed 6.3.2.3 Step3: Maximum Likelihood Estimates, if the test p-value is less than a significant level of 0.05, then it is inferred that there is evidence to reject the null hypothesis. The null hypothesis is that there is no association between highway class and the factor being compared against while controlling for the crash severity level. If the p-value is less than 0.05, the null hypothesis is rejected and it is judged that there is dependence between highway class and the factor.

P-values varied for the comparison of each highway class and each crash severity level. As shown in the top of table in Figure 6-11, the p-value among the inter-categories is less than 0.05. Therefore, the comparison within categories could be done. However, the p-value of crash severity level 3, 'bruises and abrasion', was 0.1096 and higher than 0.05. Therefore, the comparison of each other factor related to severity level 3 has no meaning statistically. On the other hand, the comparisons between crash severity level and highway class except the comparison related to severity level 3 had statistical meaning.

As shown at the bottom of Figure 6-12, the p-values of the comparison between highway class 3 and severity level 2, and highway class 3 and severity level 3 were 0.9004 and 0.1552, respectively. This meant that comparison of these combinations could not be made since there was statistically no meaning of those comparisons.

6.3.3.2 Other Factors

Through chi-square test and CATMOD, it was possible to identify primary crash contributors of eleven factors. Table 6-6 and Table 6-7 show a summary of primary and secondary contributors of the ten main factors, respectively, which were obtained from the detailed analysis results included in Appendix D.

The primary contributors of ten factors showed some uniform patterns except for the day of the week (see Table D-5), but the secondary contributors didn't have any important patterns in their significance. The primary contributors by severity level and highway class were as follows: alignment section (straight), light condition (day light), involved number of vehicles involved (two vehicle or one vehicle), collision type (same direction, single vehicle, or opposite turn), surface condition (dry), weather condition (clear), time zone (9AM-5PM), estimated speed (high estimated speed, e.g., 55 mph, on Non-Interstate highways) and accident type (MV-MV, i.e., multi-vehicle crashes or ran off road). The result of the primary contributors unexpectedly indicated that work zone crashes took place at locations where driving conditions are not inferior, meaning, by implication, that good conditions may have given the drivers a false sense of safety. The secondary contributors have a wider range of contributors depending on highway class and crash severity level contributions.

Table 6-6 Primary Contributors to Work Zone Crashes

Main Factor	Highway Class	No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
Alignment	RI,UI,RNI,UNI	Straight	Straight	Straight	Straight	Straight
Light Condition	RI,UI,RNI,UNI	Daylight	Daylight	Daylight	Daylight	Daylight
Number of Vehicle	RI	2	2	1	1	1
	UI,RNI,UNI	2	2	2	2	2
Main Contributor	Difference Not Significant					
Collision Type	RI	Same Direction	Same Direction	Single Vehicle	Single Vehicle	Single Vehicle
	UI	Same Direction	Same Direction	Same Direction	Same Direction	Same Direction
	RNI	Same Direction	Same Direction	Same Direction	Single Vehicle	Opposite Turns
	UNI	Same Direction	Same Direction	Same Direction	Same Direction	Opposite Turns
Day of the Week*	RI	Friday	Friday	Monday	Thursday	Saturday
	UI	Saturday	Friday	Friday	Tuesday	Friday
	RNI	Wednesday	Tuesday/Wednesday	Wednesday	Thursday	Saturday
	UNI	Wednesday	Tuesday	Wednesday	Saturday	Wednesday
Surface Condition	RI,UI,RNI,UNI	Dry	Dry	Dry	Dry	Dry
Weather Condition	RI,UI,RNI,UNI	Clear	Clear	Clear	Clear	Clear
Time	RI,UI,RNI,UNI	9AM – 5PM	9AM – 5PM	9AM – 5PM	9AM – 5PM	9AM – 5PM
Estimated Speed	RI	55mph	55mph	55mph	65mph	55mph
	UI	55mph	55mph	55mph	55mph	55mph
	RNI	5mph	5mph	5mph	5mph	40mph
	UNI	5mph	5mph	5mph	5mph	5mph/45mph
Accident Type	RI	MV-MV	MV-MV	MV-MV	Ran off road	Ran off road
	UI,RNI,UNI	MV-MV	MV-MV	MV-MV	MV-MV	MV-MV

*: Not a coherent trend

Table 6-7 Secondary Contributor to Work Zone Crashes

Main Factor	Highway Class	No Injury	Possible Injury	Bruises and Abrasion	BBBB	**Fatal**
Alignment	RI	Grade Straight	Grade Straight	Grade Straight	Grade Straight	Curve Grade
	UI,UNI	Grade Straight	Grade Straight	Grade Straight	Grade Straight	Curve Level
	RNI	Grade Straight	Grade Straight	Grade Straight	Grade Straight	Grade Straight
Light Condition	RI,UI,RNI,UNI	Darkness	Darkness	Darkness	Darkness	Darkness
# of Vehicle	RI	1	1	2	2	2
	UI	3	3	3	3	4
	RNI	3	3	3	1	1
	UNI	3	3	3	3	1
Main Contributor	Impossible to compare					
Collision Type	RI	Single Vehicle	Single Vehicle	Same Direction	Same Direction	Opposite Turns
	UI	Single Vehicle	Single Vehicle	Single Vehicle	Opposite Turns	Single Vehicle
	RNI	Single Vehicle	Opposite Turns	Single Vehicle	Opposite Turns	Single Vehicle
	UNI	One Vehicle	Opposite Turns	Opposite Turns	Opposite Turns	Single Vehicle
Day of the Week*	RI	Monday	Thursday	Friday/ Sunday	Sunday	Sunday
	UI	Wednesday	Thursday	Thursday	Thursday	Tuesday
	RNI	Thursday	Thursday	Friday	Wednesday	Sunday
	UNI	Tuesday	Wednesday	Friday	Thursday	Monday/ Thursday
Surface Condition	RI,UI	Wet	Wet	Snowy	Wet	Wet
	RNI	Wet	Wet	Wet	Wet	Icy
	UNI	Wet	Wet	Wet	Wet	
Weather Condition	RI,UI	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy
	RNI,UNI	Cloudy	Cloudy	Cloudy	Cloudy	
Time	RI,UI	5PM - 7PM	5PM - 7PM	7PM - 10PM	10PM - 7AM	10PM - 7AM
	RNI	5PM - 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM	10PM - 7AM
	UNI	5PM - 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM
Estimated Speed	RI	50mph	50mph	65mph	55mph	65mph/75mph
	UI	50mph	50mph	50mph	65mph	45mph/50mph
	RNI	10mph	30mph	60mph	50mph	50mph
	UNI	10mph	10mph	10mph	30mph	30mph/65mph
Accident Type	RI	Ran off road	Ran off road	Ran off road	MV-MV	MV-MV
	UI	MV-Fixed object	MV-Fixed object	MV-Fixed object	MV-Fixed object	Ran off road
	RNI	Ran off road	Ran off road	Ran off road	Ran off road	Ran off road
	UNI	MV-Fixed object	MV-Fixed object	MV-Pedestrian	Ran off road	Ran off road

*: Not a coherent trend

6.4 Chapter Summary

Based on the results of the statistical analyses mentioned in the previous sections of this chapter on work zone crash data from year 1992 to year 2004 obtained from UDOT's CARS database, the following conclusions were made:

- The analysis of descriptive statistics and NDTNC showed that the UI had the highest number of crashes and was the most dangerous among the four highway classes (RI, UI, RNI, UNI). The estimated NDTNC of the UI was the shortest (1.67days) among the four highway classes, while the RNI was the longest (3.79 days) across severity levels. This means that on average a crash takes place every 1.67 days on UI statewide. Note that standard deviation was 7.34 days, meaning that the NDTNC of UI is widely distributed.
- As far as crash severity level is concerned, the No Injury crash severity level had the highest number of crashes among the five severity levels, while the Fatal level had the fewest crashes among the five severity levels, which was as expected. The estimated mean of NDTNC at the NI level was 0.72 for UI, which was also the shortest among the five crash severity levels, while the mean of NDTNC at the Fatal level was 100.73 and the longest. The rank of the mean NDTNC across all crash severity levels was UI (1.67), UNI (2.09), RI (3.76), and RNI (3.79).
- According to the chi-square test on the frequency table, the highest number of crashes happened on UI across crash severity levels and its value was 9,602 crashes (45.46 %). The NI severity level accounted for 13,536 crashes (64.09 %) of the total number of crashes. Also, UI had the highest number of fatal crashes among the four highway classes.
- The hazard ratio analysis using Cox Regression, one of the TPHREG statistical procedure, ranked UI as the most dangerous among the four highway classes. The hazard ratio that resulted from this study was as follows: RI:UI:RNI:UNI = 0.18:10.96:0.07:1.00. Therefore, when ranked in the order of hazard ratio, the order became UI > UNI > RI > RNI. This means that UI was not only the most dangerous in terms of crash severity

level, but also had the highest occurrence of fatal crashes among the four highway classes.

- The primary contributors of ten factors showed some uniform patterns except for the day of the week (see Table D-5), but, the secondary contributors didn't have any important patterns in their significance. The primary contributors by severity level and highway class were as follows: alignment section (straight), light condition (day light), involved number of vehicles involved (two vehicle or one vehicle), collision type (same direction, single vehicle, or opposite turn), surface condition (dry), weather condition (clear), time zone (9AM-5PM), estimated speed (high estimated speed, e.g., 55 mph, on Non-Interstate highways) and accident type (MV-MV, i.e., multi-vehicle crashes or ran off road). The result of the primary contributors unexpectedly indicated that work zone crashes took place at locations where driving conditions are not inferior, meaning, by implication, that good conditions may have given the drivers a false sense of safety. The secondary contributors have a wider range of contributors depending on highway class and crash severity level contributions.

In conclusion, among the four highway classes, the UI highway class had the highest number of crashes and was statistically identified as the most dangerous in all analyses performed, including the common descriptive statistical analysis, the estimation of the NDTNC, and the hazard ratio analysis. The analysis on the primary contributor analysis by highway class and crash severity level revealed that the primary contributors of the ten factors analyzed in this study manifested some patterns, for instance 'straight' alignment, and 'dry' surface condition, but the secondary contributors did not have any obvious patterns.

7 Cost Analysis of Work Zone Traffic Control Methods

7.1 Major Factors Affecting Traffic Control Costs

Major factors affecting direct construction costs including traffic control cost are construction type, construction duration, construction scale, road (highway) type, construction location, construction time and others, such as detour and bypass arrangements. Especially, construction type, construction scale, and construction location affect the quantity of traffic control devices. Table 7-1 shows the major factors affecting construction costs including traffic control costs.

Table 7-1 Major Factors Affecting Construction Costs

Major Factors	Number of Types	Breakdown of Types
Construction Types	4 types	Reconstruction, rehabilitation, repair, and maintenance
Construction Duration	3 types	Short term (within one month), mid term (one month to six months), and long term (over six months)
Construction Scales (Degree of Impact on Traffic Flow)	4 types	Road closure (full control), one way closure (full control), lane closure (partial control), and no obstruction
Road Types	5 types	Freeway (urban area or rural area), arterials (urban area or rural area) and others (local street)
Construction Location	6 types	Main lane, turn lane (left or right), shoulder, roadside, others
Construction Time	4 types	Season, weekday/weekend, peak/non-peak, day/night
Others	3 types	Detour, bypass, etc

7.2 Analysis of Traffic Control Costs Performed in This Study

In this study, many limitations existed on calculating or estimating traffic control costs of various projects. Therefore, the analysis of traffic control costs in this study was limited to the two case study sites.

Table 7-2 shows the data obtained on traffic control and other costs of the two case study sites. Main traffic control devices of the US-6 and I-15 work zones were barrels and concrete Jersey barriers, respectively. The traffic control costs per mile of the two work zones were 0.04 million dollars per mile at the US-6 site and 0.12 million dollars per mile at the I-15 site. Also, the traffic control costs per month per mile for the US-6 and I-15 work zones were 0.55 thousand dollars per month per mile at the US-6 site and 5.91 thousand dollars per month per mile at the I-15 site, respectively.

Obviously, the cost of using concrete barriers would be intuitively more expensive than that of barrels, but the lack of detailed cost data prohibited detailed analysis. Hence, if detailed cost analyses on traffic control devices are desired, records on traffic control costs must be gathered and other costs maintained.

Table 7-2 Data on Traffic Control Coast and Other Costs

		Unit	US-6	I-15
Construction Duration		Months	16.5	15
Span of Work Zone		Miles	3.72	11.1
Main Works			Rehabilitation & Reconstruction	Same as left
			Widening, hot-mix asphalt paving, chip seal	One lane open on each direction, partial closing
Main Traffic Control Devices			Barrel (Drums)	Concrete barriers
Total Construction	Cost	M$	10.80	19.85
	Cost per mile	M$/mile	2.90	1.79
	Cost per year	M$/year	7.85	15.88
	Cost per month	M$/month	0.65	1.32
	Cost per month and mile	K$/month, mile	0.04	0.09
Traffic Control	Cost	M$	0.15	1.33
	Cost per mile	M$/mile	0.04	0.12
	Cost per year	M$/year	0.11	1.06
	Cost per month	K$/month	9.09	88.67
	Cost per month and mile	K$/month, mile	0.55	5.91

7.3 Chapter Summary

The three objectives of traffic control for construction and maintenance are (a) high level of safety, (b) minimal congestion, and (c) access to work area. Due to the lack of detailed information on traffic control devices used at the two case study sites, the cost analysis on traffic control devices initially sought for these two case study sites could not be performed. However, the major factors and procedures which should be used for traffic control cost analysis were identified and evaluated.

As one of the main parts of construction cost, traffic control cost is affected by construction type, construction duration, construction scale, road (highway) type, construction location, construction time, construction phasing and others. These pieces of information must be kept for detailed cost analyses of traffic control devices if statistical analyses of traffic control costs are desired.

One of the objectives of traffic control cost analysis was to select the best traffic control alternative among the proposed alternatives which would help the contractor maintain a safe work area and stay on schedule. In order to execute traffic control cost analysis, the following method consisting of five distinct steps could be considered (Beacher et al., 2004):

1. Identify Traffic Control Costs.
2. Determine Effectiveness.
3. Determine Weights for Objectives.
4. Compute Cost-Effectiveness Scores.
5. Select Preferred Option.

8 Comparison of Crash Characteristics between Construction Time and Non-Construction Time

8.1 Introduction

Traffic control in work zones must satisfy dichotomous goals: protecting the work zone to keep it as safe as possible and keeping a free flow of traffic through the work zones. In order to establish effective and efficient traffic safety policies for work zones, traffic safety engineers need to know whether crash frequencies or crash rates are higher during construction time than during non-construction time at the same highway sections. Although many researches in the past showed that crash frequencies were higher during construction time than during non-construction time at the same highway sections, the traffic engineers at UDOT were not sure whether such a trend was universally true for all highway sections.

Therefore, in order to ascertain whether crash rates during construction time are higher than those during non-construction time at the same highway sections, a data mining of crashes in work zones was conducted. It was found that the difference in the mean crash rates during construction time and during non-construction time was not statistically significant at the 95% confidence level.

The purposes of this chapter are to compare the mean crash rates by highway class between construction time and non-construction time at the same highway segments, and to provide supporting data for improving traffic safety in work zones.

8.2 Methodology

8.2.1 Data Collection and Reduction

UDOT identified 528 road construction projects between 2002 and 2005, and crash records related to these construction projects were collected. Using the procedure discussed below, 202 projects were eventually selected further analyses, which consisted of 45 projects on rural interstate highways, 26 projects on urban interstate highways, 65 projects on rural non-interstate highways, and 66 projects on urban non-interstate highways. The following actions were taken for data reduction to select the projects for the study:

1) Add milepost and route number to the work zone,
2) Remove projects with unclear mileposts (station number, no milepost),
3) Remove projects with unclear route numbers,
4) Remove projects that spanned into 2006 because there was no crash data available in UDOT's crash record system at the time of the study,
5) Remove projects where construction lasted less than one month,
6) Remove projects that had the same beginning and ending mile posts, and
7) Remove projects that did not have crash data.

8.2.2 Grouping of Data for Construction and Non-construction Times

In order to avoid the bias of non-construction crash data caused by road environment and traffic condition compared with the crash data of construction times, crash data for non-construction times were obtained from the same highway sections where data for construction times were available. The crash data used to represent non-construction times were the average crash rates of the three years prior to the construction time began.

8.2.3 Calculation of Crash Rate

In order to calculate the crash rate using vehicle miles traveled (VMT), Annual Average Daily Traffic (AADT) and the length of the highway affected by each of the chosen 202 construction projects were needed. AADTs were estimated using UDOT data available through the Traffic on Utah Highway website (2007). The length of each project was obtained by identifying the beginning and ending mileposts of the project during the data sorting process. Also, the crash records by severity level for each project were obtained from UDOT's CARS website (2006). Crash rates of each project were categorized by highway class.

8.2.4 Analysis Method

Crash rates of the 202 projects were analyzed using statistical analysis tools such as SPSS (2003) and S-plus (2005). Descriptive statistical analyses (mean, standard deviation, confidential interval, and histogram), a paired t-test, a two-way ANOVA, and a Tukey test were performed using two major factors: i.e., highway class and crash severity level. Highway classes were composed of Rural Interstate (RI) highways, Urban Interstate (UI) highways, Rural Non-Interstate (RNI) highways and Urban Non-Interstate (UNI) highways. Crash severity levels consisted of No injury (NI), Possible Injury (PI), Bruises and Abrasion (BA), Broken Bones and Bleeding Blood (BBBB), Fatal, and a combination of BBBB and Fatal crash severity levels (BBBB+Fatal). The last combined crash severity level was added upon request by UDOT.

8.3 Analysis Result

8.3.1 Summary of Descriptive Statistics

Table 8-1 presents a summary of descriptive statistics by crash severity level with highway class as a factor. The difference in mean crash rates between construction and non-construction times is computed by subtracting the mean crash rate during non-construction time from the mean crash rate during construction time.

As shown in Table 8-1, the mean crash rate is higher during construction time (2.5456 crashes per MVMT) than during non-construction time (1.8780 crashes per MVMT) for all crash levels and highway classes combined. However, note that their standard deviations are very large, indicating that the difference between the two crash rates may not be statistically significant.

The effect of highway class on all crash levels combined is shown in the next output row in Table 8-1. The difference in crash rates between construction time and non-construction time is higher on rural highways (0.2273 crashes per MVMT for RI and 1.815 crashes per MVMT for RNI) than on urban highways (0.0598 crashes per MVMT for UI and 0.073 crashes per MVMT for UNI). No special trend was found in the difference of crash rates between construction time and non-construction time on either interstate highways or non-interstate highways. The difference in crash rates between construction time and non-construction time on RNI highways was the highest with 1.8195 crashes per MVMT. This indicates that more attention should be given to traffic safety treatments in work zones on rural highways than on urban highways.

Table 8-1 then presents the effect of highway class on mean crash rates between construction time and non-construction time for each crash severity level considered by highway class. Most of the difference in mean crash rates between construction and non-construction time were positive. UNI highways were the only highway class that had negative difference in mean crash rates between construction time and non-construction time, except for the UI highway class in the PI crash severity level that had the largest value of negative difference in mean crash rates (-0.2358 MVMT). The difference in mean crash rates for NI, BBBB, Fatal, and BBBB+Fatal crash levels turned out to be negative; the differences in mean crash rates of the UNI highway class for the PI and BA crash severity levels were positive. Negative values in the difference in mean crash rates between construction time and non-construction time meant that crash rates were lower during construction time, which countered the hypothesis of this study.

If the difference is negative, the mean crash mean crash rate during construction time was less than the mean crash rate during non-construction time, implying that the highway section were safer during construction time. On the other hand, if the difference is positive, the mean crash rate during construction time is greater than the mean crash rate during non-construction time. However, this does not guarantee that the difference of mean crash rates between non-construction time and during construction time is statistically greater than zero. The distribution of crash rates must be taken into account to make the decision.

Table 8-1 Summary of Descriptive Statistics by Crash Severity Level

			N	Minimum	Maximum	**Mean**	Std Deviation
Total		Construction	202	0.0466	93.0344	2.5456	6.9756
		Non-construction	202	0.0007	45.6348	1.8780	5.1976
		Difference	202	-41.9965	92.8787	**0.6677**	8.0878
Total	RI	Construction	45	0.0466	1.8866	0.6495	0.4139
		Non-construction	45	0.0014	2.1372	0.4222	0.4844
		Difference	45	-0.8801	1.8306	**0.2273**	0.4822
	UI	Construction	26	0.2924	16.8869	1.7327	3.1288
		Non-construction	26	0.0007	18.3215	1.6730	4.2523
		Difference	26	-16.5107	4.2030	**0.0598**	3.5868
	RNI	Construction	65	0.0662	93.0344	3.0054	11.4237
		Non-construction	65	0.0013	19.6011	1.1859	2.6646
		Difference	65	-17.6674	92.8787	**1.8195**	11.7984
	UNI	Construction	66	0.5004	22.1638	3.7059	3.7095
		Non-construction	66	0.0059	45.6348	3.6329	8.0215
		Difference	66	-41.9965	14.3646	**0.0730**	7.6252
No Injury (NI)	RI	Construction	45	0.0466	1.2034	0.3858	0.2748
		Non-construction	45	0.0010	1.3586	0.2725	0.3485
		Difference	45	-0.7746	1.1434	**0.1133**	0.3391
	UI	Construction	26	0.2249	11.2579	1.1929	2.0916
		Non-construction	26	0.0005	14.8862	1.1628	3.1138
		Difference	26	-13.3252	4.9160	**0.0301**	2.9553
	RNI	Construction	65	0.0000	24.6268	1.4414	3.1370
		Non-construction	65	0.0000	11.9519	0.7520	1.6497
		Difference	65	-10.8589	24.5749	**0.6894**	3.5515
	UNI	Construction	66	0.0000	14.1042	2.2493	2.5262
		Non-construction	66	0.0033	32.4435	2.3841	5.2534
		Difference	66	-30.4844	8.6350	**-0.1349**	5.1568
Possible Injury (PI)	RI	Construction	45	0.0000	0.4922	0.1058	0.1109
		Non-construction	45	0.0000	0.2326	0.0440	0.0554
		Difference	45	-0.0879	0.4779	**0.0619**	0.1004
	UI	Construction	26	0.0000	0.3931	0.1845	0.1200
		Non-construction	26	0.0000	6.3420	0.4203	1.3098
		Difference	26	-6.3420	0.3684	**-0.2358**	1.3460
	RNI	Construction	65	0.0000	3.1850	0.2092	0.4841
		Non-construction	65	0.0000	3.8246	0.1587	0.5246
		Difference	65	-3.4883	3.1850	**0.0505**	0.6739
	UNI	Construction	66	0.0000	6.3325	0.9179	1.1531
		Non-construction	66	0.0000	8.7809	0.7315	1.7713
		Difference	66	-7.9894	4.5846	**0.1863**	1.7205
Bruises & Abrasion (BA)	RI	Construction	45	0.0000	0.2146	0.0770	0.0552
		Non-construction	45	0.0001	0.1832	0.0438	0.0440
		Difference	45	-0.1329	0.1887	**0.0332**	0.0644
	UI	Construction	26	0.0000	5.6290	0.2883	1.0905
		Non-construction	26	0.0000	0.8588	0.0764	0.1960
		Difference	26	-0.7964	5.6290	**0.2119**	1.1250
	RNI	Construction	65	0.0000	1.6885	0.1508	0.2719
		Non-construction	65	0.0000	1.9123	0.1350	0.2983
		Difference	65	-1.8282	1.1648	**0.0158**	0.3724
	UNI	Construction	66	0.0000	1.9662	0.3469	0.3598
		Non-construction	66	0.0000	3.4591	0.2915	0.5828
		Difference	66	-2.8260	1.9662	**0.0554**	0.6252

Table 8-1 (Continued)

			N	Minimum	Maximum	**Mean**	Std Deviation
Broken Bone and Bleeding Blood (BBBB)	RI	Construction	45	0.0000	0.2982	0.0729	0.0711
		Non-construction	45	0.0000	0.3816	0.0554	0.0717
		Difference	45	-0.3314	0.1805	**0.0175**	0.0876
	UI	Construction	26	0.0000	0.8347	0.0650	0.1588
		Non-construction	26	0.0000	0.0987	0.0125	0.0226
		Difference	26	-0.0177	0.8347	**0.0525**	0.1611
	RNI	Construction	65	0.0000	68.4076	1.1889	8.4732
		Non-construction	65	0.0000	1.9123	0.1290	0.3024
		Difference	65	-1.5760	68.4076	**1.0599**	8.4946
	UNI	Construction	66	0.0000	1.6302	0.1886	0.2685
		Non-construction	66	0.0000	3.9913	0.2133	0.6065
		Difference	66	-3.5164	1.5274	**-0.0247**	0.6006
Fatal	RI	Construction	45	0.0000	0.0503	0.0079	0.0129
		Non-construction	45	0.0000	0.0475	0.0065	0.0118
		Difference	45	-0.0475	0.0442	**0.0014**	0.0147
	UI	Construction	26	0.0000	0.0137	0.0019	0.0035
		Non-construction	26	0.0000	0.0071	0.0009	0.0020
		Difference	26	-0.0071	0.0135	**0.0010**	0.0042
	RNI	Construction	65	0.0000	0.2470	0.0151	0.0425
		Non-construction	65	0.0000	0.2045	0.0112	0.0369
		Difference	65	-0.2045	0.2462	**0.0039**	0.0585
	UNI	Construction	66	0.0000	0.0625	0.0032	0.0101
		Non-construction	66	0.0000	0.5322	0.0124	0.0667
		Difference	66	-0.5322	0.0622	**-0.0092**	0.0678
Broken Bone and Bleeding Blood (BBBB) + Fatal	RI	Construction	45	0.0000	0.3124	0.0808	0.0748
		Non-construction	45	0.0000	0.4274	0.0619	0.0795
		Difference	45	-0.3269	0.2175	**0.0189**	0.0910
	UI	Construction	26	0.0000	0.8347	0.0669	0.1586
		Non-construction	26	0.0000	0.1058	0.0135	0.0242
		Difference	26	-0.0247	0.8347	**0.0535**	0.1613
	RNI	Construction	65	0.0000	68.4076	1.2040	8.4715
		Non-construction	65	0.0000	1.9123	0.1402	0.3055
		Difference	65	-1.4919	68.4076	**1.0638**	8.4944
	UNI	Construction	66	0.0000	1.6302	0.1918	0.2679
		Non-construction	66	0.0000	4.5235	0.2257	0.6589
		Difference	66	-4.0486	1.5274	**-0.0339**	0.6501

To clearly show the variation of the differences in crash rates, visual presentations of the distribution of crash rates can be used, including such graphic data presentation methods as histogram, box plots, scatter plots, and so forth. Figure 8-1 shows the histograms of the difference in mean crash rates between construction time and non-construction time by highway class. Although the differences in mean crash rates found in Table 8-1 are clearly greater than zero at the most of time, we can easily see that the crux points of the distribution of difference in mean crash rates between construction time and non-construction time in Figure 8-1 are located near zero, except for RNI highways. Figure 8-1 clearly indicates that the distribution of the differences in mean crash rates between construction time and non-construction time requires further analyses.

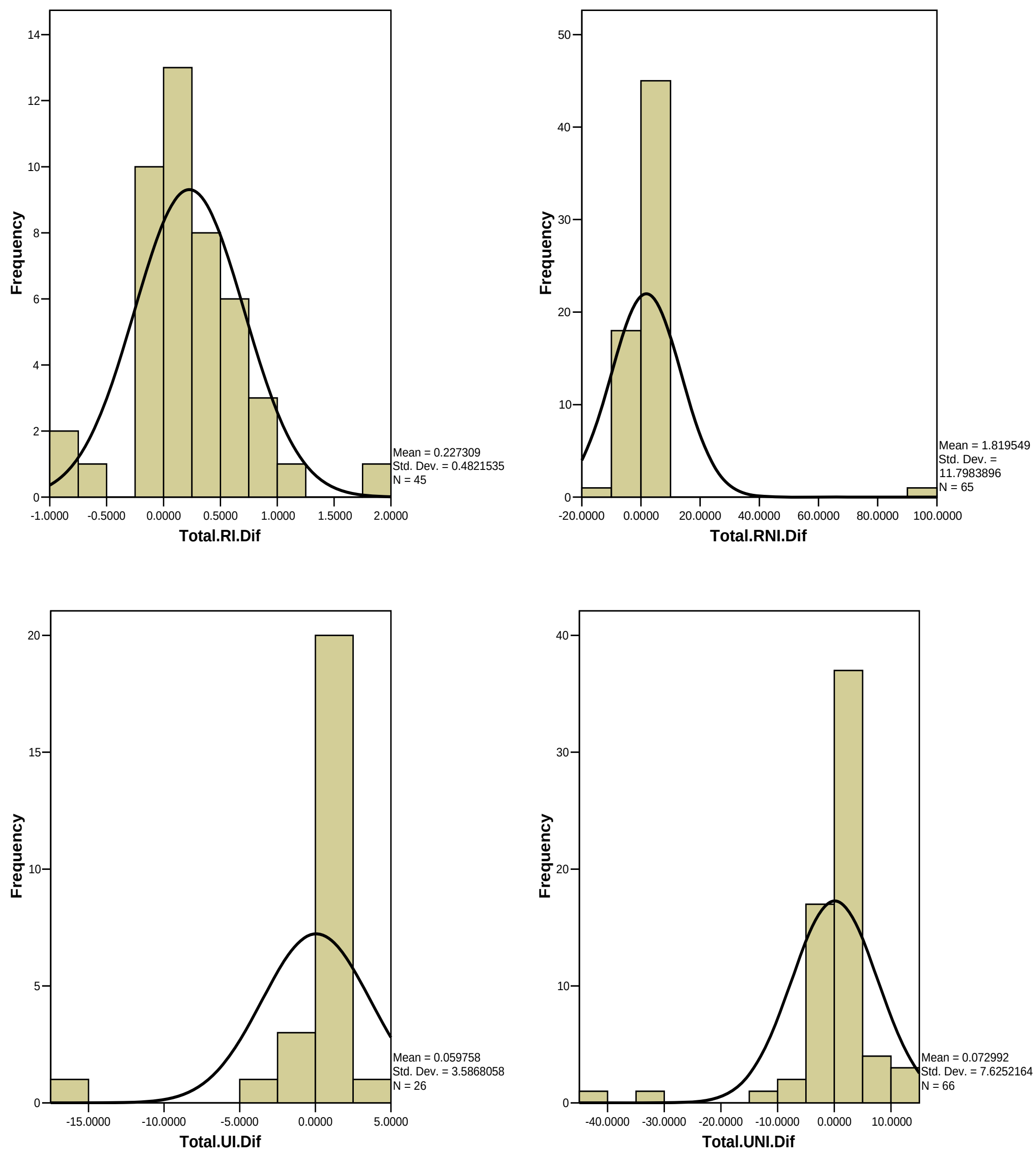


Figure 8-1 Histogram of the Difference in Mean Crash rates of Construction and Non-construction Time by Road Functional Class

8.3.2 Paired t-Test

Paired t-test is a method for testing if a new process or treatment is superior to a current process on the same subjects (27). This concept applies to the analysis of crash rates on highway sections where construction projects took place and to the effect of construction projects on crash rates for the same highway sections.

Data are paired because the subject in this case is a location and a treatment is to make the location under construction. There is a one-to-one correspondence between the values in the two samples. That is, if X_1, X_2, ... , X_n and Y_1, Y_2, ... , Y_n are the two samples, then X_i corresponds to Y_i. For paired samples, the difference of the two samples (X_i - Y_i) is calculated. The variances of the two samples may be assumed to be equal. Equal variances yield somewhat simpler formulas, although with modern computers this is no longer a significant issue. The null hypothesis is in the form that the difference between the two population means is equal to some constant, $\mu_1 - \mu_2 = d_o$ where the constant d_o is the desired threshold. The null hypothesis defined for this analysis is $\mu_1 - \mu_2 = 0$, that is, $\mu_1 = \mu_2$, and the alternative hypothesis is $\mu_1 \neq \mu_2$ (27). The t-statistics is defined as follows;

$$t = \frac{\overline{X} - \overline{Y}}{\sqrt{s_1^2/N_1 + s_2^2/N_2}} \qquad \textbf{(Equation 8-1)}$$

where N_1 and N_2 are the sample sizes, $\overline{X}$ and $\overline{Y}$ are the sample means, and s_1^2 and s_2^2 are the sample variances. If equal variances are assumed, then the formula reduces to:

$$t = \frac{\overline{X} - \overline{Y}}{s_p\sqrt{1/N_1 + 1/N_2}} \qquad \textbf{(Equation 8-2)}$$

where

$$s_p^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2} \qquad \textbf{(Equation 8-3)}$$

Figure 8-2 shows an SPSS output for the analysis of total crash rates. The p-value for this paired t-test between the total crash rates during construction time (Construction (C.Total)) and non-construction time (Non-Construction (N.C.Total)) was 0.242, which was greater than the significance level 0.05 set for the analysis. This means that the difference in mean crash rates between construction time and non-construction time was not statistically significant and we could not reject the null hypothesis $\mu_1 = \mu_2$ with the 95% confidence level at the aggregated level comparison. Hence, we concluded that paired t-tests for more disaggregate levels are needed, that is, for each highway class and severity level combinations.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Construction (C.Total)	2.546	202	6.976	.491
	Non-Construction (NC.Total)	1.878	202	5.198	.366

Paired Samples Correlations

		N	Correlation	Significance
Pair 1	C.Total & NC.Total	202	.141	.045

Paired Samples Statistics

	Paired Difference					t	df	Significance (p-value) (two-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 C.Total & NC.Total	.668	8.088	.569	-.454	1.790	1.173	201	.242

Figure 8-2 SPSS Output for the Paired Sample t-Test for Total Crash Rates

Table 8-2 shows the results of paired t-tests in terms of p-values for all severity level and highway class combinations. All p-values - except those for the RI highway class for all crash severity levels combined (Total) and the NI, PI, and

BA crash severity level – were greater than 0.05 (95% significance level). Therefore, we concluded that the crash rates were statistically the same between construction time and non-construction time except for the NI, PI, BA, and BBBB severity levels for RI highways.

Table 8-2 Paired t-test Result (p-values)

	Total	RI	RNI	UI	UNI
Total	0.242	**0.003***	0.218	0.933	0.938
NI	0.430	**0.030***	0.123	0.959	0.832
PI	0.459	**0.000***	0.548	0.380	0.382
BA	0.155	**0.001***	0.733	0.346	0.474
BBBB	0.313	0.187	0.318	0.109	0.740
Fatal	0.717	0.523	0.593	0.235	0.273
BBBB + Fatal	0.315	0.170	0.316	0.103	0.673

* Numbers in bold font shows that these values are less than p=0.05.

8.3.3 Two-way ANOVA

ANOVA is a general technique that can be used to test the hypothesis that the means among two or more groups are equal, under the assumption that the sampled populations are normally distributed.[28] In order to find out the interaction among highway classes for the difference between the crash rates during construction time and non-construction time, a two-way ANOVA was applied to the data. The two-way ANOVA model for the general layout is written as,

$$Y_{ijk} = \mu + \tau_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$$
$$i = 1,2,\cdots,b; k = 1,2,\cdots,r$$
(Equation 8-4)

where μ is the overall mean response, τ_i is the effect due to the i-th level of factor A, β_j is the effect due to the j-th level of factor B and γ_{ij} is the effect due to any interaction between the i-th level of A and the j-th level of B. At this point, consider the levels of factor A and of factor B chosen for the experiment to be the only levels of interest to the experimenter such as highway class for the difference between the crash rates during construction time and non-construction time. The factors A and B are said to be fixed factors and the model is a fixed-effects model. When an

$a \times b$ factorial experiment is conducted with an equal number of observations per treatment combination, the total sum of squares is partitioned as:

$$SS\ (total) = SS\ (A) + SS\ (B) + SS\ (A \times B) + SSE \qquad \textbf{(Equation 8-5)}$$

where AB represents the interaction between factor A and factor B. Usually, for the two-way ANOVA, the possible null hypotheses are:

- There is no difference in the means of factor A
- There is no difference in the means of factor B
- There is no interaction between factors A and B

In this analysis, factor A was a covariate "construction time" (CT), which was consisted of two levels: "before construction crash rate" (BC) and the difference in crash rates" (DIF). Factor B was a "highway class" (HC), which was consisted of four levels (RI, RNI, UI, and UNI).

- There is no difference in the means of factor A (*CT*).
- There is no difference in the means of factor B (*HC*).
- There is no interaction between factors A and B (*CT HHC*).

Figure 8-3 shows the results of a two-way ANOVA of the interaction among highway classes into the covariance between crash rates during non-construction time and the difference of crash rates (total crash rates during construction time – total crash rates during non-construction time). The p-value for CT*HC was 0.075, which was greater than the selected significance level of 0.05, meaning that the hypothesis "There is no interaction between factors A and B" could not be rejected at the 95% confidence level. This result was favorable for our analysis because we could then analyze the effect of factors A and B individually.

Univariate Analysis of Variance (Total)

Between-Subjects Factors

		N
CT	BC	202
	DIF	202
HC	RI	90
	RNI	130
	UI	52
	UNI	132

Tests of Between-Subjects Effects

Dependent Variable: CR

Source	Type III Sum of Squares	df	Mean Square	F
Corrected Model	606.728[a]	7	86.675	1.894
Intercept	453.262	1	453.262	9.906
CT	122.858	1	122.858	2.685
HC	140.781	3	46.927	1.026
CT * HC	318.000	3	106.000	2.317
Error	18119.317	396	45.756	
Total	19380.559	404		
Corrected Total	18726.045	403		

a. R Squared = .032 (Adjusted R Squared = .015)

Figure 8-3 Results of Two-Way ANOVA Results Using SPSS

Table 8-3 shows the results of the two-way ANOVA by crash severity level. Note that the values in the Total column are exactly the same as the values in the Significance column in Figure 3. The p-values of CT, HC and CT*H*HC for all crash levels combined and for each crash severity level. Most p-values are more than 0.05 as shown in Table 8-3 except the cases discussed below.

The p-value for CT was less than 0.05 at the NI and PI crash severity levels. The p-value for HC was less than 0.05 only at the PI crash severity level. The p-value for CT×HC was less than 0.05 at the NI crash severity level. This indicates that the difference in mean crash rates in the NI and PI crash severity level is affected by the level of crash rates during non-construction time. Highway class does not statistically affect the difference in mean crash rates at different crash severity levels except at the PI crash severity level. The effect of the interaction CT*H*HC is significant at the NI crash severity level, but it is not significant at the PI crash severity level. Hence, mean crash rates at the NI and PI crash severity levels are the ones that have affected the outcomes of the statistical analyses up to this point.

Table 8-3 Two-Way ANOVA Results by (p-values)

	Total	NI	PI	BA	BBBB	Fatal	BBBB + Fatal
Corrected Model	0.069	0.003	0.004	0.031	0.699	0.257	0.696
Intercept	0.002	0.001	0.004	0.000	0.302	0.170	0.294
Construction Time (CT)	0.102	0.011	0.009	0.271	0.636	0.098	0.653
Highway Class (HC)	0.381	0.288	0.026	0.171	0.547	0.743	0.540
CT * HC	0.075	0.023	0.154	0.097	0.544	0.416	0.539

8.3.4 Tukey Test

The findings up to this point, however, do not tell what combinations of factors are statistically significant. In order to identify the source of significant difference, a Tukey test was applied as the last statistical analysis of the study. This allows us to examine the detailed results of the two-way ANOVA analysis of the difference in mean crash rates between construction time and non-construction times and to test all possible pair-wise differences of the means to determine if at least one difference is significantly different from 0.

The Tukey method applies simultaneously to the set of all pair-wise comparisons $\mu_i = \mu_j$ and uses the studentized range distribution (Ramsey and Schafer, 2002). Suppose we have r independent observations $y_1, y_2, \ldots, y_r$ from a normal distribution with mean μ and variance σ^2. Let w be the range for this set, i.e., the maximum minus the minimum. Now suppose that we have an estimate s^2 of the variance σ^2 which is based on v degrees of freedom and is independent of the y_i. The studentized range is defined as $q_{r,v} = w/s$. The Tukey confidence limits for all pair-wise comparisons with confidence coefficient of at least 1-α are:

$$(\overline{y_{i\cdot}} - \overline{y_{j\cdot}}) \pm \frac{1}{\sqrt{2}} q_{\alpha,r,} N - r \hat{\sigma}_\varepsilon \sqrt{\frac{2}{n}} \quad i, j = 1, \cdots, r; i \neq j$$

(Equation 8-6)

Note that the sample sizes must be equal when using the studentized range approach. This requirement was met by using work zone locations for which both non-construction and construction crash records are available (Ramsey and Schafer, 2002).

Figure 8-4 presents the p-values of a Tukey test on the difference in mean crash rates with crash records of all severity levels aggregated. The top portion of Figure 8-4 presents the results of a Tukey test of mean crash rates for all the crash severity levels aggregated. None of the p-values were less than 0.05, indicating that the difference in mean crash rates did not vary significantly across highway classes. This means that even if mean crash rates do increase during construction time, the increase is not statistically significant at the 95% confidence level. This corresponds to the results of the two-way ANOVA test.

The bottom portion of Figure 8-4 shows the results of a Tukey test of mean crash rates during non-construction time, which represents average crash rates for the three years prior to the beginning of construction work; the mean crash rates are used as the covariate of the analysis. Two pairs were found to have p-values less than 0.05. The differences in mean crash rates between RI (HC-1) and UNI (HC-4) were statistically significant (p-value = 0.007 < α = 0.05), and the differences between UI (HC-3) and UNI (HC-4) (p-value = 0.032 < α = 0.05) were statistically significant at the 95 % confidence level. The rest had no statistical difference at the 95% confidence level.

After a Tukey test was performed on aggregated data, the differences in mean crash rates were evaluated for all crash severity levels. Table 8-4 shows the results (p-values) of Tukey tests by severity level. The top part of Table 8-4 shows results of a Tukey test on the difference in mean crash rates between construction time and non-construction time. Since no p-values of the difference in mean crash rates between construction time and non-construction time were less than 0.05, we concluded that highway class did not statistically affect the difference in mean crash rates. Hence, there were no strong reasons to reject the null hypothesis, and the difference in mean crash rates was statistically zero for the compared pairs.

On the other hand, the crash rates during non-construction time showed a different trend (see the lower part of Table 8-4). In lower crash severity levels such as NI, PI, and BA, a few combinations of highway classes turned out to have p-values less than 0.05. It was found that the mean crash rates of lower severity levels NI, PI, and BA were statistically different at the 95% confidence level. The bottom part of Table 8-4 showed the difference in mean crash rates between RI (HC-1) and UNI (HC-4) and between UI (HC-2) and UNI (HC-4). These pairs were reciprocated, as seen in Table 8-4.

As for higher severity levels, such as BBBB, Fatal, and BBBB + Fatal, highway class did not affect mean crash rates at the highway sections that were used for the analysis.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Highway Class	(J) Highway Class	Mean Difference (I-J)	Standard Error	Significance (p-value)	95% Confidence Interval	
						Lower Bound	Upper Bound
Difference (Total)	1	2	–1.592	1.573	0.742	–5.667	2.482
		3	0.168	1.998	1.000	–5.008	5.343
		4	0.154	1.568	1.000	–3.908	4.216
	2	1	1.592	1.573	0.742	–2.482	5.667
		3	1.760	1.882	0.786	–3.116	6.635
		4	1.747	1.417	0.607	–1.925	5.418
	3	1	–0.168	1.998	1.000	–5.343	5.008
		2	–1.760	1.882	0.786	–6.635	3.116
		4	–0.013	1.878	1.000	–4.878	4.852
	4	1	–0.154	1.568	1.000	–4.216	3.908
		2	–1.747	1.417	0.607	–5.418	1.925
		3	0.013	1.878	1.000	–4.852	4.878
Non-Construction (Total)	1	2	–0.764	0.984	0.865	–3.314	1.786
		3	–1.251	1.250	0.749	–4.490	1.988
		4	**–3.211**	0.981	**0.007**	–5.753	–0.669
	2	1	0.764	0.984	0.865	–1.786	3.314
		3	–0.487	1.178	0.976	–3.538	2.564
		4	**–2.447**	0.887	**0.032**	–4.745	–0.149
	3	1	1.251	1.250	0.749	–1.988	4.490
		2	0.487	1.178	0.976	–2.564	3.538
		4	–1.960	1.175	0.343	–5.004	1.085
	4	1	**3.211**	0.981	**0.007**	0.669	5.753
		2	**2.447**	0.887	**0.032**	0.149	4.745
		3	1.960	1.175	0.343	–1.085	5.004

Bold: The mean difference is significant at the 0.05 level.

Figure 8-4 Tukey Test Results for Total Crash Rates

Table 4: Results of the Tukey Test Across Crash Severity Level (p-Values)

Dependent Variable	(I) HC	(J) HC	Total	NI	PI	BA	BBBB	Fatal	BBBB + Fatal
Difference (Construction - Non-Construction)	1	2	0.742	0.856	1	0.999	0.684	0.995	0.769
		3	1	1	0.726	0.592	1	1	0.965
		4	1	0.986	0.945	0.997	1	0.711	0.18
	2	1	0.742	0.856	1	0.999	0.684	0.995	0.769
		3	0.786	0.872	0.713	0.462	0.807	0.995	0.559
		4	0.607	0.587	0.909	0.98	0.576	0.467	0.645
	3	1	1	1	0.726	0.592	1	1	0.965
		2	0.786	0.872	0.713	0.462	0.807	0.995	0.559
		4	1	0.998	0.399	0.647	1	0.828	0.128
	4	1	1	0.986	0.945	0.997	1	0.711	0.18
		2	0.607	0.587	0.909	0.98	0.576	0.467	0.645
		3	1	0.998	0.399	0.647	1	0.828	0.128
Non-construction	1	2	0.865	0.881	0.956	0.607	0.764	0.947	0.682
		3	0.749	0.702	0.55	0.986	0.97	0.956	1
		4	**0.007**	**0.007**	**0.013**	**0.005**	0.158	0.897	1
	2	1	0.865	0.881	0.956	0.607	0.764	0.947	0.682
		3	0.976	0.952	0.764	0.911	0.571	0.748	0.805
		4	**0.032**	**0.029**	**0.026**	0.091	0.603	0.998	0.566
	3	1	0.749	0.702	0.55	0.986	0.97	0.956	1
		2	0.976	0.952	0.764	0.911	0.571	0.748	0.805
		4	0.343	0.394	0.651	0.074	0.119	0.671	1
	4	1	**0.007**	**0.007**	**0.013**	**0.005**	0.158	0.897	1
		2	**0.032**	**0.029**	**0.026**	0.091	0.603	0.998	0.566
		3	0.343	0.394	0.651	0.074	0.119	0.671	1

8.4 Chapter Summary

Many research studies reported that crash frequencies in construction zones were higher than the crash frequencies in non-construction zones, but those studies did not shed light on whether crash rates by highway class were significantly different between construction time and non-construction time at the same highway sections. The present study focused on answering this last question.

The analysis of descriptive statistics (means and standard deviations) showed that the difference in mean crash rates between construction and non-construction times, except UNI highways, was positive, meaning mean crash rates increase during construction time. The difference in mean crash rates for construction projects on UNI highways was negative, meaning that mean crash rates were lower during construction time on UNI highways. Mean crash rates decreased during construction time for the NI, BBBB, Fatal, BBBB + Fatal crash severity levels on UNI highways (see Table 8-1).

The paired t-test of crash rates between construction time and non-construction time showed that there is no statistical difference between the mean crash rates among highway classes except at lower severity levels (NI, PI, BA) on RI highways (see Table 8-2). According to the results of the descriptive statistics and the paired t-test, we were not able to conclude at the 95% confidence level that the crash rates during construction time were higher than the crash rates during non-construction time.

Hence, two-way ANOVA and Tukey tests were performed to further evaluate the effect of highway class on the difference in mean crash rates between construction and non-construction times. It was found that the effect of highway class was statistically not significant on the difference in mean crash rates during construction and non-construction times. However, crash rates during non-construction time had significant effect on the difference in mean crash rates between construction and non-construction times (see Table 8-3). The difference in crash rates during non-construction time between highway classes RI and UNI and between highway classes RNI and UNI was statistically significant at lower crash severity levels (see Table 8-4).

These analysis results indicate that the trend of higher crash rates during construction time reported by previous work zone safety–related studies was not universally valid and statistically not supported by Utah's crash records.

It should be mentioned that this analysis did not consider the work zone traffic control strategies applied to the work zones because there was no data available on this issue for the 202 construction project sites analyzed in the study. Our assumption was that the contractors followed UDOT's standard procedure for work zone traffic control. And, in fact, it can be said that the contractors' observance of UDOT's standard work zone traffic control procedures was instrumental in keeping the level of traffic safety during construction time as high as the safety level during non-construction time. Hence, it is recommended that

UDOT continue to enforce compliance with the work zone traffic control guidelines by contractors in order to maintain work zones safe.

9 Summary of Work Zone Crash Analysis Tasks

9.1 Major Findings from Literature Review

9.1.1 Crash Frequency in Work zone

Wilde et al (1999) compared crash frequencies at work zones to the normal, that is, non-work zone condition. Their analysis showed that crash occurrence in work zone increased from 6.8 % to 119 %.

Also, Garber et al. (2002) studied the relationship between the number of crashes and the length of work zone. They developed a linear relationship between the number of crashes and the length of work zone, ADT, and lane width. Overall, they reported that crash frequencies in work zones increased compared to those in the non-construction area: the activity area accounted for 70% of the crashes, followed by the transition area (13%), and the advance warning area (10%). The buffer and the termination areas accounted for 5% and for 2%, respectively.

Many previous studies on the crash frequency in work zones showed that the number of crashes during construction increased compared to during non-construction time. Also, many researches proved that the activity area in work zone was the most dangerous sub-area. More scientific and comparative study on crash characteristics between during construction time and during non-construction time is needed.

9.1.2 Characteristics of Fatal Crashes in Work Zones in Texas

Schrock et al. (2004) analyzed the characteristics of fatal crashes in work zones in Texas using the crash data for year 2003 to 2005. The followings are their analysis results:

- By functional highway class: Interstate highway (31%), US highway (34%), State highway (21%), farm to market highway (13%), and others (1%);
- By sub-area work zone: Longitudinal buffer area and activity area (77%), transition area (15%), termination area (5%), advance warning area (3%);
- By work zone activity: Construction activity (35%), resurfacing activity (23%), bridgework (13%), maintenance activity (12%), other works (1%), traffic signal installation (11%);
- By light condition(for fatal crashes): Night (52%), daylight (45%), dawn/dusk (3%), and
- By vehicle type: Large trucks were involved in 29% of the crashes.

Even though Schrock et al. (2004) analyzed the work zone crashes with various factors, their study had some limitations indicating the concentration on special crash severity and the focus on Texas area. Therefore, a similar research which focuses on Utah with all severity levels is needed to guarantee work zone traffic safety in Utah.

9.1.3 Evaluation of Traffic Control Devices in Work Zones

Carlson et al (2000) divided traffic control devices into two categories: high priority measures and low/medium priority measures. High priority traffic control measures included larger/fluorescent signs, high-visibility clothing, opposing traffic lane dividers, portable changeable message sign, portable rumble strips, drone radar, radar speed display, sign attachments, temporary stop bar, and vehicle visibility improvements. And low/medium priority measures were direction indicator barricades, flashing stop/slow paddle, intrusion alarm, lane narrowing, portable traffic signal, queue length detector, remote driven vehicle, and water-filled barriers.

Fontaine et al (2000) analyzed the effect of traffic control devices and reported the following:

- Speed display trailers. Reduced the average speed by 5mph and the percent of vehicle exceeding speed limit.
- Portable variable message signs (VMS). Produced 1-2 mph reduction in average speed in the work zone. When VMSs were used, half as many cars were in the closed lane approximately 1000 ft from the work zone taper compared to not using VMSs.
- Fluorescent yellow-green worker vests and hard hat covers. Fluorescent yellow-green garments were more visible than orange garments against common work zone backgrounds because they have a greater luminance (brightness) than orange garments.
- Fluorescent orange sign. Received positive comments from the workers and the drivers on increased visibility of the signs. Primary benefits of fluorescence occur at dawn and dusk.
- Drone radars. Produced a 1-2 mph reduction in average speed.
- Retro-reflective vehicle visibility improvement. Received positive comments from the workers on visibility of flagger vehicles. Primary benefit of this device would occur at night.
- Dynamic speed display signs (DSDS). They helped reduce average speed by 9 mph at the school speed limit according to Rose (2003).

Many previous researches on traffic control device in work zone were based on the effects of some special types of traffic control devices and relied on some special analysis method such as interview survey. In order to lead the optimal investment of traffic control device for work zone safety, detailed and various researches need to focus on the economic and social effects of traffic control devices in work zones.

9.2 Main Crash Characteristics of the Two Case Study Sites

Two work zones were chosen to review the temporal and spatial crash characteristics by traffic control device. One of the work zones was located on US 6, south of Spanish Fork and had barrels as its major traffic control device, while the other was located on I-15, south of Payson and had concrete Jersey barriers as its main traffic control device. The major works of the two work zones were rehabilitation & reconstruction.

9.2.1 General Summary of Analysis on Crash Frequency and Crash Rate

Some of the literature on this topic reported that crash frequencies in work zones during construction increased and had higher crash frequencies than those in non-work zone (Garber and Zhao, 2006), (Hall and Lorenz, 1989). However, the two case study sites used in this study showed quite different trends. Overall crash rates (crashes per 100 MVMT) during construction at the two study sites were lower than the crash rates before construction at the same locations. However, more fatal crashes happened during construction than before construction, indicating the need for measures to reduce fatality during construction time. These trends are shown in Table 9-1. Obviously, the data from the two case study sites are not adequate to generalize the trends; however, the values in Table 9-1 are interesting to observe.

Table 9-1 Crash Frequency and Crash Rates of Two Study Sites (Before→During→After)

Crash Rates	Unit	US-6 Study Site	I-15 Study Site
Number of crashes per year	crashes/year	22.0→19.35→6.00	38.33→40.80→40.72
Crashes per 100 MVMT	crashes/100 MVMT	244.61→210.80→66.88	80.00→79.01→40.72
Fatal Crashes per 100 MVMT	crashes/100 MVMT	3.71→8.43→8.36	1.39→3.10→0.00

9.2.2 Construction Cost

The total construction cost and the traffic control cost of the two sites are shown in Table 9-2. The total construction cost per mile of the US-6 study site was higher than the total construction cost per mile of the I-15 study site. However, the traffic control cost per mile for the US-6 study site is much lower than that of the I-15 study site because of the difference in the type of traffic control used. Obviously, using concrete Jersey barriers as the major traffic control device was more expensive than using barrels. Traffic control cost is not always related to the total construction cost or the magnitude of construction.

Table 9-2 Construction Cost and Traffic Control Cost of the Two Case Study Sites

Cost	Unit	US-6 Site	I-15 Site
Total construction cost per mile	M$/mile	2.90	1.79
Traffic control cost per mile	M$/mile	0.04	0.12
Traffic control cost per month and mile	K$/mile/month	0.55	5.91

9.2.3 Spatial and Temporal Crash Analyses

9.2.3.1 Crash Characteristics of Before, During, and After Construction

Previous studies have shown that the active area (construction zone) in the work zone had higher crash rates than the other work zone components such as the advance area, transition area, buffer area, etc. However, the two sites analyzed in this study showed that crash rates in the buffer area (upstream or downstream 1-mile zone from the work zone) during construction increased, compared to the crash rates before construction even though the total crash rates of the work zones during construction didn't increase compared to the rates before construction. Fatal crash rates, however, did increase at the two study sites during construction compared to before construction as shown in Table 9-1.

9.2.3.2 Crash Characteristics during Construction

Among the work zone components, work zone, downstream and upstream 1-mile, and 5-mile zones measured from the work zone during construction were found to be most crash prone at the two case study sites. That is to say, the advanced warning zones and transition/buffer zones of the two sites were found to have the highest crash rates. Crash rates were the highest at the upstream or downstream 1-mile to 2-mile zone from the work zone for both the US-6 and I-15 study sites: 62.74 MVMT in upstream 1-mile zone, 8.43 MVMT in work zone, and 31.37 MVMT in downstream 1-mile zone for the US-6 study site; and 17.18 MVMT in upstream 2-mile zone, 3.10 MVMT in work zone, and 34.56 MVMT in downstream 2-mile zone for the I-15 study site.

The one mile section in the west or east direction of the work zone at the US-6 study site had the highest crash rates before, during and after construction. The mid-section of the construction zone at the I-15 study site had the highest crash rate before and during construction and at both ends after construction.

Even though there is only a small difference in the construction tasks of the two case study sites, the highest crash frequency happened in May (at both study sites), and June (at the US-6 study site), and August (at the I-15 study site), respectively. Therefore, it can be concluded that the transition period from spring to summer and the summer season were the most dangerous months in the year at the two case study sites.

Also, crash frequency was highest on weekends (Saturday at the US-6 study site, Sunday and Tuesday at the I-15 study site). Because this trend exists regardless of traffic control devices, it can be concluded that weekend construction requires special attention.

The time of the day with the highest crash rate was 5:00 PM to 6:00 PM at the US-6 study site and 11:00 AM to noon and 3 PM to 4:00 PM at the I-15 study site. The latter result means that the highest crash frequency does not always happen during morning or evening peak periods. Note that the two case study sites were located in rural areas.

9.2.4 Analyses of Other Factors

The analyses between the crash rates and other factors such as light condition, traffic control method, alignment, weather condition, and surface condition were done for the two case study sites to identify major contributing factors to crash occurrences. The results are summarized below:

- Light condition: Over 96 % of the entire crashes happened in the ‘daylight’ and ‘dark street or highway, not lighted’ light conditions at both sites. All fatal crashes happened in the ‘daylight’ and ‘dark street or highway, not lighted’ light conditions.
- Traffic control: The highest crash rates happened in the ‘traffic lane marked’ traffic control type for before, during, and after construction. Especially, during construction, there were many crashes recorded under the ‘no passing lanes’ at the US-6 study site. At the I-15 study site, crash rates were the highest in the ‘construction or work area’. Note that crashes took place the highest in the work zone during construction at the two case study sites.
- Alignment: The effects of alignment varied at different locations in the work zones. The highest crash rate was recorded in the ‘curve grade’ section followed by the ‘straight and level’ alignment section at the US-6 study site. The highest crash rate was recorded in the ‘straight and level’ alignment section, followed by the ‘grade straight’ alignment section at the I-15 study site.
- Weather condition: Most of the crashes happened in the ‘clear’, ‘snowing’, and ‘cloudy’ weather conditions. For instance, during construction at the US-6 study site, crash rates in the ‘cloudy’ weather condition accounted for the higher percentage (24.0%) than before and after construction (6.1% and 11.1%, respectively).
- Surface condition: Most of the crashes took place in the ‘dry’ and ‘snow’ surface conditions.
- Vehicle involvement: Most of the crashes were a ‘single vehicle’ crashes (80% of the crashes at the US-6 study site and 67% at the I-15 study site).
- Crash type: The major crash types vary between the two study sites. Most of the crashes at the US-6 study site were ‘MV-Wild Animal’

crashes (36%), 'ran off roadway-right (MV-Fixed Object)' crashes (16%), and 'MV-MV' crashes (20%). Most of the crashes at the I-15 study site were 'MV-MV' (32%), 'ran off roadway-right' (24%), and 'ran off roadway-left' (14%) crashes.

9.2.5 Directional analysis

9.2.5.1 Crashes

These were significant differences between the two case study sites. The crash rates for the east (upgrade) and west (downgrade) directions at the US-6 study site were 59.75 per 100 MVMT crashes in the eastbound direction and 119.5 crashes per 100 MVMT in the westbound direction. Hence, the westbound direction was more dangerous than the eastbound direction.

On the other hand, the crash rates of both directions, northbound and southbound directions, at the I-15 study site, had similar crash rates. During construction, crash rates of the northbound and the southbound directions were 37.18 crashes per 100 MVMT and 38.73 crashes per 100 MVMT, respectively.

9.2.5.2 Spatial and temporal crash analysis

The spatial distributions of crash occurrence in the two work zones were similar to that of the entire trend. Especially, at the I-15 study site crashes concentrated in the end segments of the work zone. As for fatal crashes, they occurred in the westbound direction at the US-6 study site and in both directions at the study I-15 site. The temporal characteristics of crash occurrences at the two sites were similar to that of the entire crash trend, as discussed before.

9.2.5.3 Other Factors

With a few exceptions, the analysis of the relationship between crash rates and other factors such as light condition, traffic control method, alignment, weather condition and surface condition of the two sites showed results similar to those of the overall trends, discussed above. Some exceptions were summarized below;

- Control type: During construction, the control type that had the highest number of crashes was ‘no control present’ in the westbound direction at the US-6 study site.
- Weather and surface condition: Many crashes at the I-15 study site happened during the ‘snow’ weather condition and during the ‘snowy’ surface condition.
- Crash type: Many crashes in the westbound direction at the US-6 study site were ‘MV-fixed objects’ and ‘Ran off roadway-left’ type crashes. At the I-15 study site, many crashes in the southbound direction were ‘MV-fixed object’ and ‘ran-off roadway- left’ type crashes.

9.2.6 Construction Phase

9.2.6.1 Crashes

At the two case study sites, phase II had the highest crash rate among the three construction phases. Main construction types, duration, and crash rates of the three phases at the US-6 study site varied significantly. The main construction type, and crash rate of each phase at the US-6 study site were: widening (13 months) and 211.13 crashes per 100 MVMT for phase I; rehabilitation by removing existing pavement (1 month) and 392.10 crashes per 100 MVMT for phase II; and chip-seal (1 month) and 130.70 crashes per 100 MVMT for phase III. The main construction type, duration, and crash rate of each phase at the I-15 study site were: inside lane construction (4.4 months) and 73.94 crashes per 100 MVMT for phase I; dynamic compaction (3.3 month) and 98.59 crashes per 100 MVMT for phase II; inside lane construction (7.3 month) and 73.22 crashes per 100 MVMT for phase III.

In summary, phase II at the US-6 study site had the highest crash rate in spite of its short duration as well as phase II at the I-15 work zone.

9.2.6.2 Spatial and temporal crash analysis

The spatial and temporal crash characteristics of the two case study sites were similar to the crash characteristics found from the analysis of entire work zone crash data of all crash data at each study site. There are a few exceptions as shown below;

- All Crashes in phase II at the US-6 case study site happened in the mid-section of the work zone. The crash rates at the I-15 case study site were the highest in phase II and III in the end one mile zone of the north bound direction.
- At the US-6 study site, only phase I had severe crashes (phase II and phase III had only 'no injury' crashes), while at the I-15 study site, only phase III had the fatal crash.
- Unlike the trends found in the entire analysis of entire crash data, crashes in phase I and II at the US-6 study site happened only on Tuesdays, Thursdays, and Fridays. The highest number of crash occurrence of each phase on I-15 had different days of the week: during phase I on Tuesdays, during phase II on Thursdays, and during phase III on Sundays.

9.2.6.3 Other Factors

With a few exceptions, the analyses between the crash rates and the other factors by phase resulted in the findings similar to those of the analyses of the entire crash data at the two case study sites. (See section 9.2.4) The exceptions identified in the analyses were summarized below:

- Control type: Phase II of the US-6 study site had a high number of 'no passing lanes' control type crashes whereas the types of control with highest crash occurrences at the I-15 study site were different by phase (Phase I and II – 'construction or work area' control type, phase III – 'traffic lanes marked' control type).

- Alignment: Most of the crashes in phase II at the US-6 study site happened in the 'straight and level' alignment sections while the highest crash rates at the I-15 study site were different by phase (Phase I and III - the 'grade straight', 'straight and level' sections and phase II – the 'straight and level' sections).
- Weather condition: Crashes in phase I at the US-6 study site had only in the 'snow' weather condition while many crashes in phase II and III at the I-15 study site happened in the 'snowing' weather condition
- Surface condition: Phase II and III at the US-6 study site had crashes only in the 'dry' surface condition. On the other hand, all phases at the I-15 study site had crashes in all surface conditions.
- Crash type: The 'ran-off roadway left and right' crash type had the highest number of occurrence in phase III at the I-15 study site. On the other hand, the 'MV-animal (wild)' crash type had the highest number of occurrence in phase III at the US-6 study site.

9.2.7 Seasonal analysis

The annualized average number of crashes and the crash rates for the three summer months were larger than those for the entire construction period. Other crash trends such as spatial and temporal crash distributions and the findings of the other factors were similar to the entire analysis period. (See section 9.2.4)

9.3 Main Crash Characteristics from the Full-Scale Data Mining Analysis

9.3.1 Estimation of the Number of Days to Next Crash

In terms of the crash severity level, the mean number of days to next crash (NDTNC) of the 'no injury' crash level (0.72 day per crash) was the shortest among the five crash severity levels while the mean number of days to next 'fatal' crash (100.73 days) was the longest. In terms of highway class, the mean number of days to next crash of the Urban Interstate highway class (1.67days) was the shortest among the four highway classes while that of the Rural Non-Interstate highway class (3.79 days) was the longest. The rank of the mean NDTNC for each highway class was RI (3.76 days), UI (1.67 days), RNI (3.79 days), and UNI (2.09 days). Table 9-3 shows the detailed estimation of the number of days to next crash. It shows that Urban Interstate highways require continual attention to improve their safety.

Table 9-3 Detailed Estimation of the NDTNC

	Estimation Results (Mean NDTNC)
Severity across Highway Classes	'No injury' (0.72), 'Possible injury' (2.14), 'Bruises and abrasion' (6.25), 'Broken bones or bleeding bloods' (10.17), 'Fatal' (100.73)
Fatal Crashes by Highway Class	RI (121.66), UI (60.22), RNI (177.28), and UNI (102.72)
NDTNC by Highway Class (across Severity Levels)	RI (3.76), UI (1.67), RNI (3.79), and UNI (2.09)

9.3.2 Overall Test between Highway Class and Crash Severity Level

Most of the crashes (96,602 crashes) happened on UI highways which accounted for 45.46% of the total number of crashes in the data used for analysis. As for crash severity level, no injury crashes (13,536 crashes) accounted fro 64.09% of the total number of crashes. Most fatal crashes happened on UI highways. Table 9-4 shows the proportions of type of crashes in the database.

Table 9-4 Descriptive Statistics on Crashes

	Estimation Results
Severity	'No injury' (64.09%), 'Possible injury' (23.80%), 'Bruises and abrasion' (7.45%), 'BBBB' (4.28%), 'Fatal' (0.38%)
Fatal crashes	RI (1.09%), UI (0.47%), RNI (0.42%), UNI (0.38%)
Highway group	RI (6.09%), UI (45.46%), RNI (14.57%), UNI (33.88%)

9.3.3 Hazard Ratio Analysis

In the hazard ratio analysis, the hazard ratios between the highway group and the reference class were determined. Table 9-5 presents the results of the hazard ratio analysis. In this study, the reference class is UNI highway (μ_4) such as RI:UNI=0.18:1.00, UI:UNI=10.96:1.00, RNI:UNI= 0.07:1.00 for fatal crash severity level. From these values, a summary of the hazard ratio was determined RI:UI:RNI:UNI = 0.18:10.96:0.07:1.00. Hence, we can rank hazard level of highway class as UI > UNI > RI > RNI. That is to say, UI highways were the most dangerous as a highway class in terms of fatal crashes. Also, the hazard ratio of UI highways were the highest among the four highway classes at each crash severity level.

Table 9-5 Hazard Ratio Analysis Results

Severity	RI:UI:RNI:UNI	Hazard Rank	Rank1
No injury	0.6448:11.5372:0.3813:1.00	UI>UNI>RI>RNI	UI
Possible injury	0.6529:12.4747:0.4868:1.00	UI>UNI>RI>RNI	UI
Bruises and abrasion	0.5153:23.9184:0.3597:1.00	UI>UNI>RI>RNI	UI
BBBB	0.5041:7.4632:0.2771:1.00	UI>UNI>RI>RNI	UI
Fatal	0.1816:10.9604:0.0658:1.00	UI>UNI>RI>RNI	UI

9.3.4 Other Factor analysis

While the primary contributors of the ten factors showed some consistent patterns except the day of the week factor, the secondary contributors didn’t have any consistent pattern among the factors. The primary contributors by severity level and by highway class were the ‘straight’ alignment, ‘daylight’ light condition, involvement of the number of ‘two vehicles’ or ‘one vehicle’ , ‘same direction’, ‘single vehicle’ or ‘opposite turn’ collision type, ‘dry’ surface condition, ‘clear’ weather condition, occurrence of ‘9AM to 5PM’ time zone, high estimated speed (‘55 mph’) on interstate highways and low estimated speed (‘5mph’) in non-interstate highway, and ‘’MV-MV’ or ‘ran off road’ crash type. However, secondary contributors were different among the severity levels and the highway classes.

9.4 Comparison of the Crash Characteristics between Construction Time and Non-construction Time in Work Zones

The analysis of descriptive statistics (mean and standard deviation) showed that mean crash rates during construction time were higher than during non-construction time except for UNI highways. The difference in mean crash rates between construction time and non-construction time on UNI highways was negative at all crash severity levels such as NI, PI, BBBB, Fatal, BBBB + Fatal, indicating that crash rates declined on the average during construction time on UNI highways.

The paired t-test of crash rates between construction time and non-construction time showed that there was no statistically significant difference between the mean crash rates among the four highway classes except at lower severity levels on RI highways. Hence, the crash rates during construction time were not statistically higher than during non-construction time

Also, the two-way ANOVA and Tukey test performed in this study proved that the effect of all highway classes on the difference in crash rates did not exist during construction time. During non-construction time, a couple of comparisons, namely RI versus UNI and RNI versus UNI, had a statistically significant difference in crash rate, but they affected mainly lower crash severity levels such as NI, PI, and BA.

In conclusion, the following findings were obtained based on the Paired t-test, two-way ANOVA and Tukey.

- As for the differences in mean crash rates across highway classes, the differences in mean crash rates among the rural highways were higher than urban highways.
- There was no statistical difference in the mean crash rates between construction time and non-construction time across highway classes.

These results may imply that the current UDOT guidelines for traffic control in work zones have been effective to maintain the safety level of traffic during construction time as high as the safety level during non-construction time.

9.5 Chapter Summary

This chapter first summarized the findings of previous studies on spatial and temporal analyses of work zone related crashes. According to some of the findings of previous studies, the frequency of the work zone crashes depended on various types of traffic control in work zones. In general, many studies reported some increase in crash rates during construction time.

Main crash characteristics of the two study sites were summarized in terms of construction cost, general crash trends in terms of crash frequencies and crash rates, spatial and temporal crash rates, crash characteristics by direction, crash characteristics by construction phase, and seasonal differences.

In addition, the primary crash characteristics found in the full-scale data mining analysis and the results of the comparison of crash characteristics between construction time and non-construction time in work zones were summarized. These findings are used for preparing the guidelines for traffic safety in work zones presented in Chapter 10.

10 Guideline Development

10.1 Tools, Purposes, and Principles for Developing Guidelines

10.1.1 Basic Tools for Developing Guidelines

The traffic safety improvement guidelines for work zones presented in this chapter were prepared based on the findings from the analyses conducted in the study which included:

- An exploratory data mining analysis consisting of spatial and temporal analyses of crashes at the two study sites,
- A full-scale data mining and analysis of work zone crashes by highway class and crash severity level, and
- A comparison of crash characteristics between construction time and non-construction time.

The preparation of comprehensive safety guidelines for the use of various types of traffic control devices was constrained by the availability of detailed data. However, the findings from the analyses of these two case study sites provided insight into the potential effectiveness of different traffic control devices on work zone traffic safety.

10.1.2 Purposes of Guideline

The purposes of developing guidelines for the use of traffic control devices to improve traffic safety at work zones are the following:

- Improve the traffic safety in work zones for road users and road providers,
- Provide a set of recommendations for maintaining a higher-level of safety through work zones, and
- Provide a set of instructions for optimal use of traffic control devices in work zones.

10.1.3 Principles

Several fundamental principles were applied to the preparation of these guidelines, which are:

- Avoid overly expanding the findings and inferences of the analyses performed in the study,
- Consider always the maximization of all potential safety benefits and the minimization of economic and social costs,
- Synthesize the findings from the general analysis and specific analyses,
- Avoid placing only one type of traffic control measure to the entire work zones: i.e., pay attention to the needs of each segment of the work zone, and
- Provide two different sets of guidelines: one containing general guidelines and the other consisting special guidelines based on the two different types of analyses conducted in this study.

10.2 Guidelines

The guidelines developed in this study consist of two types: general and special guidelines. The general guidelines were prepared based on the findings of the full scale data mining analysis and the comparison of crash characteristics between construction time and non-construction time, whereas special guidelines were prepared based on the findings of the strategies based on the analysis of traffic control strategies used at the two case study sites.

Also, prepared was the selection process of traffic control devices, as suggested by the combination of the general and specific guidelines.

10.2.1 General Guidelines

This section presents four general guidelines which were prepared based on the results of the full-scale data mining and comparative analysis of crashes during construction time and non-construction time.

- Develop a systematic traffic safety plan, especially for rural highways before construction begins, because the difference in mean crash rates between construction time and non-construction time is higher on rural highways than on urban highway.
- During construction, pay special attention to the traffic safety plan for the UI highways because UI highways have the highest crash frequency/occurrence and highest hazard ratio in all five crash severity levels.
- Use proper traffic control devices in work zones to raise driver's awareness about potential risks in work zones under certain road environment and traffic conditions, which include 'straight' alignment, 'daylight' light condition, 'dry' surface condition, 'clear weather conditions and regular work time (9:00AM to 5:00PM), and which had the highest crash rates. As these conditions were found to be significant, primary factors contributing to increasing crashes in work zones, preventive or precautionary traffic control devices need to be installed in these segments of work zones.
- Use special traffic control devices for preventing special types of crashes in work zones. The primary conditions mentioned above tell where and

when the crashes took place but they do not show the actual causes of the crashes; preventive or precautionary traffic control devices need to be installed as countermeasures. In order to reduce crashes under certain traffic and physical conditions, the following general guidelines are prepared. The factors to which the primary conditions belong to are shown in the parenthesis.

- ‘Two vehicles’ and ‘single vehicle’ (involvement of the number of vehicles): In order to reduce this type of crashes, traffic control devices that will augment driver’s awareness and promote safe distance between the two vehicles should be employed.
- ‘Same direction’ and ‘single vehicle’ (collision type): To reduce these types of crashes, traffic control devices that will augment driver’s awareness and promote safe gap distance between the two vehicles should be adopted.
- ‘Opposite turn’ (collision type): To mitigate this type of crashes, traffic control devices that will clearly separate opposing movements should be adopted.
- ‘55mph’ on interstate highways (Estimated speed): Check the amount of reduction in speed limit (10mph) in the work zone. Depending on the type of work and phasing of work, work zone speed that is commensurate with the condition of the work zone should be adopted.
- ‘MV-MV’ (crash type): Traffic control devices that will clearly separate two opposing lanes in work zones, augment driver’s awareness, and promote safe distance between the two vehicles should be employed.
- ‘Ran-off-road’ (crash type): The same guideline recommended for the ‘MV-MV’ crash type should be employed.

10.2.2 Special Guidelines

10.2.2.1 Based on the Level of Investment on Traffic Control Devices

This section presents three general guidelines which were prepared based on the level of investment on traffic control devices.

1. Invest in special traffic control devices for work zones that will help reduce the number of fatal crashes, the highest crash severity level in all work zones.
2. Allocate traffic safety investment to locations with high severity crashes or rates instead of just the number of crashes. For instance, concrete Jersey barriers cost much more than barrels do. However, the use of concrete Jersey barriers that physically separate opposing vehicles can significantly reduce the potential for head on collisions. Note, however, that the analysis done in this study showed that concrete Jersey barriers do not guarantee the reduction in severity level. Hence, decide what type of potential crashes should be reduced first and select traffic control devices that meet the needs of each work zone.
3. Choose appropriate traffic control device according to (a) traffic condition and road environment, (b) construction plan and traffic safety plan, (c) crash history across severity levels for the work zone under study, and (d) the amount of funds available to traffic control plans.

10.2.2.2 Based on Spatial and Temporal Crash Characteristics

In principle, optimal traffic control devices should be selected considering the effects of traffic control devices on specific construction types. However, estimating the benefits of each traffic control device on a given specific construction is difficult, if not impossible. Though not based on a comprehensive data set, the following specific guidelines are offered in this regard. The goals of the guidelines, prepared based on the specific crash analyses conducted in the study, are to help UDOT traffic safety personnel to identify potential countermeasures.

1. Pay special attention to several parts of work zones that were identified as having high crash rates in the spatial analysis of crash characteristics done in this study:
   - Transition/buffer area, being the most dangerous sub-area after construction (one mile zone from both ends of the work zone).
   - Buffer/transition area as the construction progresses.
   - Advanced warning area and transition/buffer area during construction.
   - Both ends of the work zone when the work zone is on a grade alignment and at the midsection when the work zone is on a level alignment.
2. Pay special attention to several parts of work zones that were identified as having high crash rates in the temporal analysis of a crash characteristics:
   - Transition period from spring to summer and the summer season (May, June and August) of the year. These months were found to be most dangerous months.
   - Weekend construction. If feasible, all possible weekend constructions should be avoided. Saturdays, Sundays and Tuesdays were found to have highest crash rates.
   - Morning and evening peak periods. These periods were not necessarily the periods of high crash occurrence. Time periods of the day with high crash rates were 11:00AM –Noon, 3:00PM-4:00PM, and 5:00PM-6:00PM.
3. Pay special attention to several parts of work zones that were found to have high crash rates in the analysis of prime contributors to crashes. This list presents the factors followed by specific types of the particular condition that produce more crashes than the rest of each factor:
   - Light condition: ‘daylight’, ‘dark street or highway, not lighted’.
   - Traffic control: ‘traffic lane marked’.

- Alignment: varied by different locations of work zones. The highest crash rates by alignment included ‘curve grade’ in grade alignment and ‘straight and level’ in level alignment.
- Weather condition: ‘clear’, ‘snowing’ and ‘cloudy’.
- Surface condition: ‘dry’ and ‘snow’.
- Vehicle involvement: ‘single vehicle’.
- Crash type: varied according to the case study sites. Most crashes in the US-6 study site involved ‘MV-Wild Animal’ crash type (36%), ‘ran off roadway-right (MV-Fixed Object)’ (16%) and ‘MV-MV’ (20%). Most of the crashes at the I-15 study site included ‘MV-MV’ (32%), ‘ran off roadway-right’ (24%), and ‘ran off roadway-left’ (14%).

4. Pay special attention to the downgrade sections in grade alignment in the work zones and to both ends of the work zones when they are on level alignment.
5. Pay special attention to such prime contributors as ‘no control present’ (control type), and ‘MV-fixed objects’ and ‘ran-off roadway left’ (crash type), on downgrade alignment and to ‘traffic lane marked’ (control type), and ‘MV-MV’ and ‘ran-off roadway right’ (crash type) on level alignment.
6. The length of each phase of the work zone affect traffic control costs; however, crash rate and crash characteristics need to be taken account.

10.2.3 Seven Steps for Selecting Traffic Control Devices in Work Zones

Optimal traffic control devices that will maximize the effect on work zone traffic safety and meet the need of specific construction types in work zones should be selected. As was mentioned in the preceding chapter, it is difficult to estimate how particular control devices used in various construction scenarios would benefit the safety of the work zones. However, based on the findings (aggregate and specific) from the analyses conducted in the study, the following seven steps are recommended to be followed to install the most effective traffic control devices for given work zones.

1. Compare the construction plan (construction type, construction duration, construction scale, construction type, detour and bypass, etc) with the traffic control plan.
2. Review crash history of at least three recent years and check especially the crash severity types that have been prevalent in the given work zone area.
3. Check the characteristics of work zones in terms of alignment and area type.
4. Examine what types of traffic control devices will meet the need of different highway classes and at the same time meet the budgetary constraints for applying traffic control devices.
5. Check the availability and economy of new technologies for traffic control in work zones including ITS technologies.
6. Consider the guidelines presented in this chapter and review the findings of the crash analyses.
7. Finally, select traffic control devices that will meet the specific needs of work zones based on the principle, the maximization of all potential safety benefits, and the minimization of economic and social costs.

11 Conclusions and Recommendations

11.1 Conclusions

The purposes of this study were to find relationship between traffic control measures and crash occurrences (type and severity) viewed from both spatial and temporal aspects and develop a set of guidelines for adopting certain types of traffic control measures given the nature and characteristics of planned work zones. In order to achieve these purposes, data on various types of work zones were needed. However, a few problems surfaced during the execution of the study due to the lack of comprehensive data necessary to achieve the goal of the study. Hence, the reader should be aware of the following points:

First, since only two case study sites were analyzed in the explanatory data mining for spatial and temporal analyses of work zone related crashes due to the lack of comprehensive construction history data, only two types of traffic control devices, barrels and concrete Jersey barriers, were analyzed.

Second, even though a cost analysis on the two case study sites was performed, the detailed cost/benefit comparisons were not made because of the lack of detailed data on the number of traffic control devices used at the two case sites. Therefore, an aggregated estimation of traffic control cost was performed for the two types of traffic control devices. Hence, general and detailed guidelines were prepared only for these types of traffic control devices.

Despite the limitations mentioned above, this portion of the study gave insights into the relationship between highway class and crash characteristics in work zones as shown below.

- Although the number of case study sties was limited to two, relationships between crash characteristics and spatial and temporal conditions in work zones were identified through a systematic and comprehensive crash analysis of the two case study sites. In general, the analysis of the two work zones showed that even though the cost of using the concrete Jersey barriers at the I-15 study site was much higher than that of using barrels at the US-6 study site. Although we cannot conclude that concrete barriers are better than barrels, we could conclude that the I-15 study site was safer than the US-6 study site. The I-15 study site has much higher cost per mile for traffic control than the US-6 study site, the ratio was 1 (the US-6 study site) to 3 (the I-15 study site), i.e. $40,323/mi against $120,909/mi. More spending on traffic control measures at the I-15 study site was resulted in lower crash rates than at the US-6 study site. The traffic safety measures provided at I-15 study site was better than the traffic safety measures provided at the US-6 study site. (See Chapter 4 Spatial and Temporal Analyses of Work Zones Related Crashes.)
- With the availability of thirteen year worth of work zone crash data from 1992 to 2004, the researchers were able to conduct a full-scale data mining, which produced general relationships between crash characteristics and spatial and temporal conditions in work zones that existed during this period. Among the four highway classes, the Urban Interstate (UI) highway class had the highest number of crashes and was statistically identified as the most dangerous in all the analyses performed in this study, including the common descriptive analysis, the estimation of the number of days to next crash (NDTNC), and the hazard ratio analysis. Also, the analysis of primary contributors to crashes by highway class and by crash severity level showed that the primary contributors of the ten factors had some patterns, but any consistent patterns were not found among the secondary contributors. (See Chapter 6 Results of Full-Scale Data Mining Analysis.)

- A comparative analysis of crash characteristics between construction time and non-construction time concluded that there was no statistically significant difference in the mean crash rates between construction time and non-construction time across highway classes at the 95% confidence level. This finding may indicate that the work zone safety measures that UDOT required the contractors to follow were helpfully in maintaining the safe environment in work zones during construction time. (See Chapter 8 Comparison of Crash Characteristics between Construction Time and Non-construction Time.)
- The above findings helped the researchers develop systematic and comprehensive guidelines for achieving the level of work zone traffic safety desired, even though there were some limitations in the analyses as indicated in the previous section. General guidelines were prepared based on the findings of the full scale data mining analysis and results of a comparison of crash characteristics between construction time and non-construction time, whereas special guidelines were prepared based on the findings from the analysis of traffic control strategies of the two case studies. (See Chapter 10 Guideline Development.)
- Seven steps for selecting traffic control devices in work zone were recommended in order to install traffic control devices which are most effective for a given work zone based on the principles of maximizing the effect on traffic safety at the work zones with a minimum required cost. (See Chapter 10 Guideline Development.)
    1. Compare the construction plan (construction type, construction duration, construction scale, construction type, detour and bypass, etc) with the traffic control plan.
    2. Review crash history of at least three recent years and check especially the crash severity types that have been prevalent in the given work zone area.
    3. Check the characteristics of work zones in terms of alignment and area type.

4. Examine what types of traffic control devices will meet the need of different highway classes and at the same time meet the budgetary constraints for applying traffic control devices.
5. Check the availability and economy of new technologies for traffic control in work zones including ITS technologies.
6. Consider the guidelines presented in this chapter and review the findings of the crash analyses.
7. Finally, select traffic control devices that will meet the specific needs of work zones based on the principle, the maximization of all potential safety benefits, and the minimization of economic and social costs.

11.2 Recommendations

In order to further improve the safety at work zones, the following recommendations are offered.

- The availability of data derives the quality and depth of analyses of work zone crash data. In order to conduct a comprehensive study on such topics like effectiveness and spatial and temporal crash occurrence characteristics, a large data set is required. It is recommended that UDOT begin accumulating necessary data. At the same time, UDOT may propose the establishment of national level data base on this topic.
- To reduce the number of crashes in work zones and further improve traffic safety in work zones, it is recommended to conduct a systematic and comprehensive factor analysis of the prime contributors to work zone crashes which were identified in this study.
- To improve traffic safety and reduce traffic congestion in work zones, further research on the application of ITS (Intelligent Transportation System) technologies to work zones is recommended.

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APPENDICES

Appendix A: Literature Review

A.1 General Characteristics of Work Zones

A.1.1 Capacity Loss and Delay Due to Work Zones

Roads are provided for the safe, smooth and efficient movement of people, goods and services. Construction work on or near the highway will affect the safety and the free movement of vehicles and pedestrians. All reasonable steps need to be taken to keep any undesirable or adverse effects to a minimum; effective traffic control is essential to achieve this goal. Traffic control and road safety involve a compromise between getting the work done as quickly and safely as possible and keeping a free flow of traffic through work zones. The primary objective of traffic control in work zones is to manage the traffic as efficiently and safely as possible for all working conditions.

As roads deteriorate, they need to be repaired or reconstructed. Some of the works done for deteriorating roads may include the following:

- Paving: milling, sealing, overlaying, concrete paving,
- Traffic control: installation, switching traffic,
- Bridge work: joints, bents, deck, demolition,
- Striping: painting, rumble strips, raised pavement markers (RPM), sensors, and
- Sign work: overhead sign bridges, lights.

Various road constructions bring barriers to traffic flow and create congestion and delay. Figure A-1 shows traffic behaviors associated with queue formation around a work zone (Land Transportation Authority (Singapore), 2001).

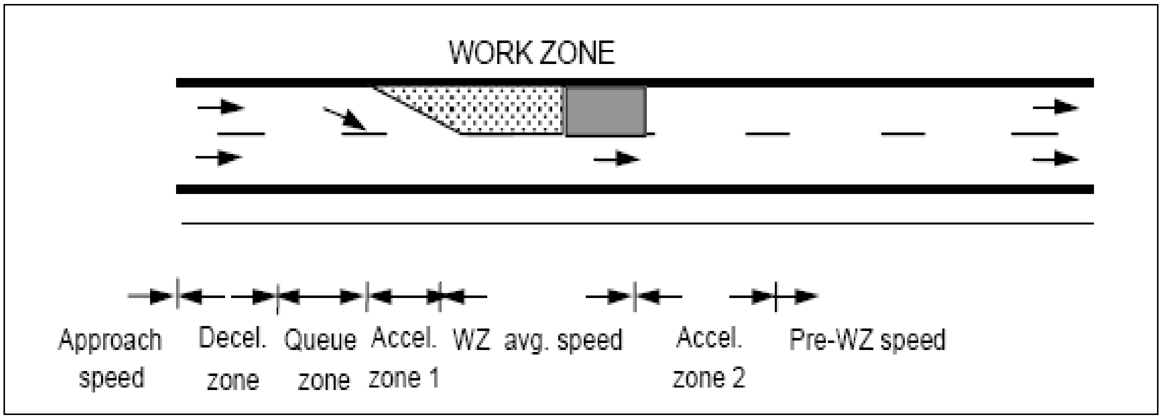

Figure A-1 Traffic Behavior Associated with Queue Formation near Work Zone

Chin et al. (2002) discussed that the capacity lost due to 585 work zones on Interstates and other expressways during 2001 would amount to an estimated 3.1 billion vehicles per year, as shown in Table A-1. The impacts of work zones are more complicated to measure since drivers often have prior knowledge of work zones and can reroute, reschedule, or cancel trips accordingly. They estimated total delay at 400-600 million vehicle-hours.

Table A-1 Capacity Loss and Delay Due to Work Zones

Impact	Quantity	Percentage (%)
Delay (million vehicle-hours)	482.1	100%
In Transition Area	435.4	90%
In Activity Area	46.6	10%
Capacity Lost (million vehicles)	3,124.5	
Delay per Work Zone (million vehicle-hours)	0.8	
Capacity Lost per Work Zone (million vehicle)	5.3	
Delay per Unit of Capacity Lost (vehicle-hours)	0.15	

Also, Chin et al. (2002) summarized the work zone mileage and bridgework by highway type during 2001, as shown in Table A-2. Reconstruction occupied the highest mileage among the four work types, and interstate highways took the highest percentage share (41.7%). Among the 346 total bridgeworks, the number of bridgework done on interstate highways was the highest.

Table A-2 Work Zone Mileage and Bridgework by Highway Type (Work Zone Mileage)

Activity	Interstate	US Highways	State Routes	Others	Total
Reconstruction	1,509	911	654	99	3,173
Resurfacing	894	1,007	739	49	2,689
Widening	291	411	221	44	967
Rehabilitation	512	209	134	3	858
Total	3,206	2,537	1,749	195	7,687
Percent of Total	41.7	33.0	22.8	2.5	100.0
Bridgework (# of bridges)	121	102	102	27	346

Also, Asim and Adeli (2003) discussed seventeen different factors impacting the work zone capacity. They were 1) percentage of trucks, 2) pavement grade, 3) number of lanes, 4) number of lane closures, 5) lane width, 6) work zone layout (lane merging, lane shifting, and crossover), 7) work intensity (work zone type), 8) length of closure, 9) work zone speed, 10) interchange effects (proximity of ramps), 11) work zone location (urban or rural), 12) work zone duration (long-term or short-term), 13) work time (daytime or night), 14) work day (weekday or weekend), 15) weather condition (sunny, rainy or snowy), 16) pavement conditions (dry, wet, or icy), and 17) driver composition (commuters or non-commuters such as tourists).

Oregon Department of Transportation (ODOT) (2002) surveyed the highway users' views and their priorities relating to highway work zones in Oregon. ODOT conducted the survey with six focus groups such as motorists, school bus drivers, fire and emergency vehicle operators, business owners, and truck drivers. From the results of the focus group discussions, two surveys were developed and conducted: one with motorists, stratified by geographic area (n = 2,002); and the other with truck drivers (n = 448). As for the results, highway users noted the lack of nighttime visibility in work zones and problems of not being able to see signs, lane markings, barriers, and construction personnel at night. Truck drivers also described difficult night work lighting plans (light plants, rotor beams, headlights, etc.). Drivers voiced a willingness to accept 12-minute to 15-minute construction related delays. Highway users in more populated regions experienced longer actual delays than those in rural areas and reported lower tolerance of acceptable delay. All groups cited the need for greater speed enforcement as an essential change for work zones. Drivers most often used signs, television, radio, and newspapers as the sources of work zone information. Still, this study raised several issues that should be addressed to reduce user inconvenience within work zones. These include: (1) greater enforcement of speeds, (2) reducing delay in the work zone, (3) better nighttime visibility and reductions in glare from construction lights, (4) making improvements to signs and striping, (5) improving flagger awareness and visibility, and (6) aligning information sources with the public's methods for obtaining information about construction.

A.1.2 Traffic Control Zones and Components in Work Zone (MUTCD)

A work zone is the distance between the first advance warning sign and the point beyond the work area where traffic is no longer affected. According to the Manual on Uniform Traffic Control Devices (MUTCD, 2003), a work zone is divided into five sub-areas 1) advanced warning area, 2) transition area, 3) buffer area, 4) activity area, and 5) termination area. Figure A-2 shows the traffic control zone and its components in a work zone.

- The advance warning area tells traffic what to expect ahead.
- The transition area moves traffic out of its normal path.
- The buffer area separates traffic from workers. The Buffer area is optional, but recommended and no equipment or material shall be placed in this area.
- The work area is set aside for workers, equipment and material storage.
- The termination area lets traffic resume normal driving.

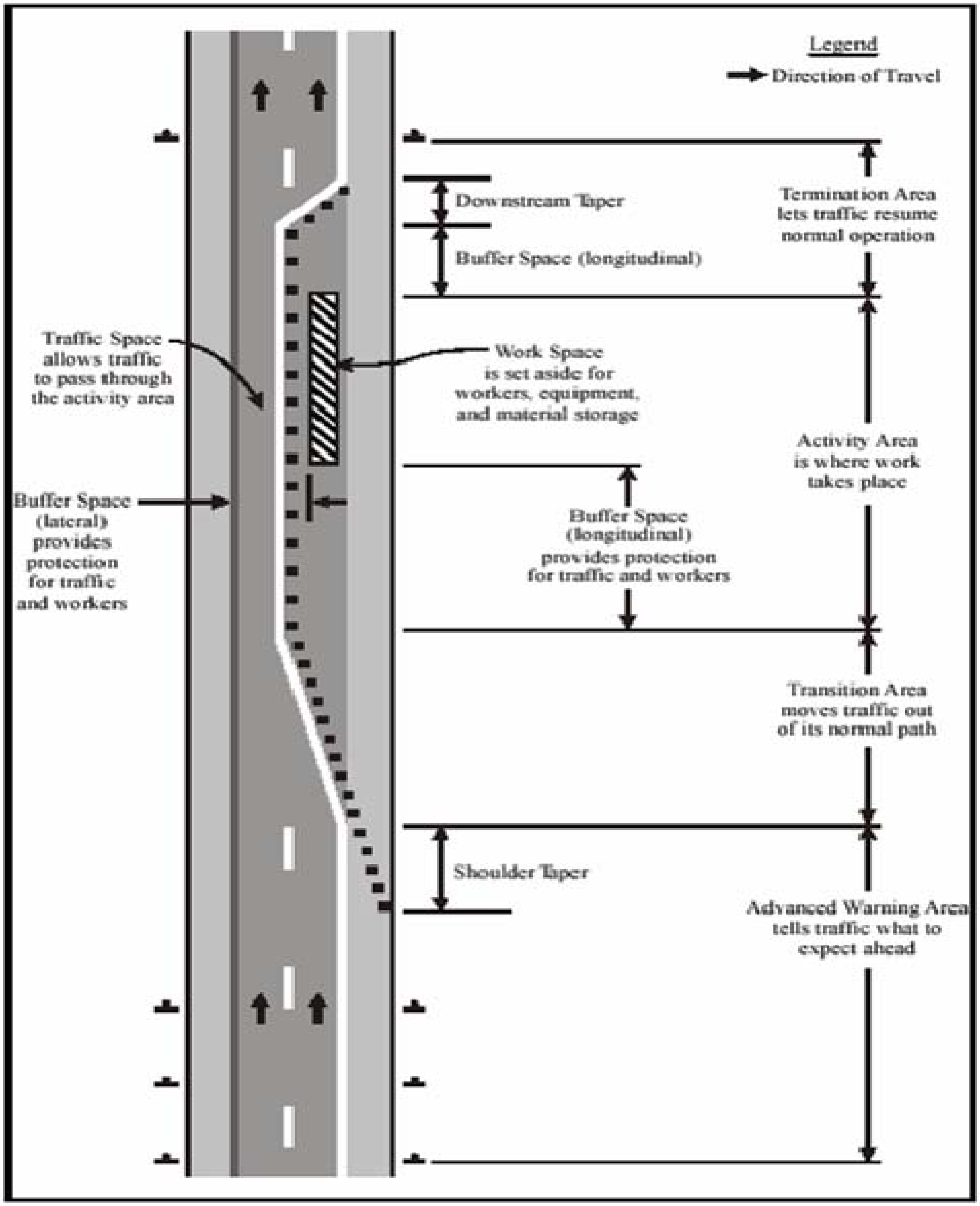

Figure A-2 Traffic Control Zone and Components in Work Zone (MUTCD, 2003)

A.1.3 Traffic Control Devices in Work Zone

A.1.3.1 Objectives and Principles of Work Zone Traffic Control

Managing traffic through a highway construction or maintenance work area is an integral part of the overall management of the work. To plan, design, and operate the temporary traffic control used in highway work activities, it is essential to first understand the goal of temporary traffic control. This can normally be stated in terms of three specific objectives (Carlson et al., 2000):

- Provide a high level of safety for workers and the public.
- Minimize congestion and community impact by maintaining levels of service at close-to-preconstruction levels.
- Provide adequate access to the roadway to complete the work efficiently while meeting the quality requirements for the completed product.

Part VI of the Manual on Uniform Traffic Control Devices (MUTCD) (2003), which establishes seven fundamental principles of work zone traffic control, is designed to ensure that the above objectives are satisfied. These principles are summarized here:

1. Traffic safety in temporary traffic control areas should be an integral and high-priority element of every project from planning through design and construction. Plans should be developed in sufficient detail to provide safety for motorists, pedestrians, workers, enforcement, and emergency personnel and equipment.
2. Traffic movement should be inhibited as little as possible.
3. Drivers and pedestrians must be guided in a clear and positive way. Positive guidance emphasizes the proper path rather than areas that are to be avoided. Existing traffic control devices should be removed if not appropriate or, in short-term work zones, other devices should be used that clearly emphasize the intended path.

4. Inspection of the traffic controls must be done on a frequent and regular basis. Crashes and other incidents should be analyzed to determine if changes in the Traffic Control Plan (TCP) are necessary.
5. Measures should be taken to ensure a safe roadside. The roadside is of particular concern in work zones because of materials and equipment that are often stored on the roadside, thereby increasing the number of hazards. There are also a number of traffic control devices that can become hazards if struck. Sidewalks and pedestrian pathways must also be protected.
6. All persons involved with the selection, placement, or maintenance of work zones should be trained in safe traffic control practices. This includes designers as well as field personnel.
7. It is necessary to maintain good public relations. Although public relations are not a primary concern of the TCP designer, special efforts can be required in the contract document, and many agencies have policies that require notice in the media prior to beginning a project.

In addition, the MUTCD points out that the laws are necessary to provide the traffic regulations needed in the work zones. These laws must permit sufficient flexibility to alter traffic control to fit changing conditions in a work zone.

A.1.3.2 Principles of Work Zone Traffic Control

A.1.3.2.1 Worker Safety Considerations

Work areas present temporary and constantly changing conditions that are unexpected by the traveler. Further, these work area conditions almost always present situations that are confusing for the driver. This creates an even higher degree of vulnerability for the personnel on or near the roadway. Of particular importance is maintaining work areas with traffic flow inhibited as little as possible, providing standard and clear traffic control devices that get the driver's attention and provide positive direction. Following are key elements of traffic control management (Carlson et al., 2000) that should be considered in any procedure for ensuring worker safety:

1. Training: All workers should be trained on how to work next to traffic in a way that minimizes their vulnerability. In addition, workers with specific traffic control responsibilities should be trained in traffic control techniques, device usage and placement.
2. Worker Clothing: Workers exposed to traffic should be attired in bright, highly visible clothing similar to that of flaggers.
3. Barriers: Barriers should be placed along the work space depending on such factors as lateral clearance of workers from adjacent traffic, speed of traffic, duration of operations, time of day and volume of traffic.
4. Speed Reduction: In highly vulnerable situations, consider reducing the speed of traffic through regulatory speed zoning, funneling, and use of police, lane reduction or flaggers.
5. Lighting: For nighttime work, lighting the work area and approaches may allow the driver better comprehension of the requirements being imposed. Care should be taken to ensure that the lighting does not cause blinding.
6. Special Devices: Judicious use of special warning and control devices may be helpful for certain difficult work area situations. These include rumble stripes, changeable message signs, hazard identification beacons, flags and warning lights.
7. Road Closure: If alternate routes are available to handle detoured traffic, the road may be closed temporarily during times of greatest worker hazard which, in addition to offering maximum worker safety, may facilitate quicker project completion and thus further reduce worker vulnerability.

Like other provisions of work area safety set forth in this part of the MUTCD, the various traffic control techniques must be applied by a qualified person after appropriate engineering studies and with sound engineering judgment and common sense.

A.1.3.2.2 Fundamental Principles for Worker Safety

There are some fundamental principles for work safety (Carlson et al., 2000) such as:

- Inspect as necessary, depending upon the complexity and length of the project. Inspect at least twice a day, and whenever you observe significant traffic pattern changes.
- Inspections, at a minimum, should be done before work begins and midday.
- Each person whose actions affect work zone safety should receive training relative to the required duties.
- Don’t assign untrained workers to the responsibility for setting up and maintaining the system.
- Be credible. Don’t advise motorists of a condition that doesn’t exist. Remove or cover all signs or devices that are not in use.
- Treat traffic control as a priority equal to the job being performed. Design a temporary traffic control system that doesn’t create confusion and is easy to navigate. Traffic movement should be restricted as little as practicable.
- Have a plan suitable to the project. Don’t bother traffic any more than necessary. Work during off peak hours. Park and work off the travel way when possible.
- Don’t expect drivers to slow down until they see some kind of activity. Drivers should be guided in a clear and obvious manner throughout the work zone.
- Don’t make drivers think, respond, brake, or maneuver rapidly.
- Develop a plan for work and emergency vehicles before it is needed.
- Reduce the time workers are exposed to traffic to minimize danger.

Traffic control's goal is to guide drivers in a definite, clear manner. There are some principles of traffic controls (Carlson et al., 2000) such as: 1) give plenty of advance notice so that drivers have time to process the warning and respond appropriately to the changes; 2) use flaggers, wearing high visibility red or orange warning garments, to supplement the other traffic control measures to improve safety; and 3) modify the traffic control system so that it remains effective under changing weather and traffic conditions.

A.1.3.3 Temporary Traffic Control Zone Devices by MUTCD

Temporary traffic control zone devices used by MUTCD (2003) are categorized into 1) signs (regulatory, warning, and guide), 2) signals, 3) hand-signaling devices, 4) channelizing devices, and 5) deflection and attention devices. The detailed size, installation place, type, characteristics, function, maintenance, and design of each traffic control device are described in Section 6 of MUTCD.

Also, Report 350 of the National Cooperative Highway Research Program (NCHRP) (1997) discussed guidelines for work zone traffic control devices. The Federal Highway Administration (FHWA) is requiring all states to have all traffic control devices in a work zone be crashworthy and to qualify as such according to the testing and acceptance guidelines of the NCHRP Report 350. The work zone traffic control devices have been classified into four categories, each having its own testing requirements and compliance date. The following is a list of the categories, examples of devices in each category (not inclusive), and the date which the category must be in compliance:

- Category 1 includes those items that are small and lightweight, such as channelizing and delineating devices. Included are items that have been in common use for many years and are known to be crashworthy by crash testing of similar devices or years of demonstrable, safe performance. These include cones, tubular posts, flexible delineator posts, and plastic drums with no attachments. These devices may be allowed for use on the NHS based on the developer's self-certification.

- Category 2 includes devices that are not expected to produce significant vehicular velocity change but may otherwise be hazardous. Examples of items in this class are barricades, portable sign supports, intrusion alarms, and plastic drums, vertical panels, or cones with lights. Testing of devices in this category will be required. However, some devices may qualify for reduced testing requirements.
- Category 3 includes hardware that is expected to cause significant velocity changes or other potentially harmful reactions to impacting vehicles. Hardware in this category must be tested to the full requirement of NCHRP 350. Concrete protection barriers, fixed sign supports, crash cushions, and other work zone devices not meeting the definitions of Category 1 or 2 are examples from this category. Concrete Protection Barriers with joints that fail to transfer tension and moment from one segment to another must be updated by October 1, 2000. Truck-mounted attenuators (TMA) and work zone crash cushions (WZCC) purchased after October 1, 1998 must comply with NCHRP 350. Existing TMA's and WZCC's can be phased out as they complete their service life.
- Category 4 includes portable or trailer-mounted devices such as flashing arrow panels, temporary traffic signals, area lighting supports, and portable changeable message signs.

A.1.4 Conclusion

MUTCD (2003) sets up some fundamental principles of installing and removing work zone traffic controls such as;

1. Safety is primary. Use whatever controls are necessary to be sure traffic and workers will be safe.
2. Signs need to be seen to be obeyed. Increase the size or height of the signs to make them more visible.

3. Increase the length of the warning area when traffic is backed up, when there is a curve, hill or other obstruction, and on high-speed, high-volume roads.
4. Allow room for the buffer space to provide additional protection of traffic and workers.
5. Additional safety and warning are needed when traffic is diverted into lanes normally used by opposing traffic.
6. Channeling devices should break or collapse when hit. Do not use concrete or other materials that may be hazardous on devices. Do not use rigid bracing for barricades.
7. All devices used at night should be reflectorized or illuminated.
8. Remove confusing pavement markings as soon as practical. Use temporary markings that can be easily removed to outline a new path.
9. If warning lights are to be used, use steady burning lights for channelization and flashing lights for warning.
10. Periodically inspect the devices. Repair or replace any damaged or missing devices.

Also, there are primary traffic control devices for better safety and mobility in a work zone. Table A-4 shows main traffic control devices according to the purpose of control in a work zone.

Table A-4 Primary Traffic Control Devices

Primary TCD	Specific TCDs
Worker –Safety Measures	High-visibility vests and clothing Vehicle treatments (retro-reflective material: two-color alternating diagonal stripes) Remotely driven vehicle Water-filled barriers Intrusion alarms: microwave intrusion alarms, infrared intrusion alarms, pneumatic tube alarms Queue length detector
Speed Control Measures	Radar drones Speed display devices Narrow lane widths
Motorist Guidance	Opposing traffic lane dividers Direction indicator barricades Portable changeable message signs
Flagger Safety Devices	Flashing stop/slow paddle (original design) Portable traffic signals Portable rumble strip Temporary stop bars

A.2 Nighttime Work Zones

A.2.1 Factors Affecting Nighttime Work Zone Crashes

Whenever an acceptable balance among the three basic objectives of work zone traffic control (high level of safety, minimum congestion, and access to work area) cannot be achieved through traditional Traffic Control Plans (TCPs) for daytime work, the feasibility of night work should be evaluated along with other traffic management strategies. However, the two basic conditions that must normally be met in order for night work to be planned are reduced traffic volumes and easy setup and removal of the traffic control devices every night (Bryden and Mace, 2003).

Shifting work activities to night hours, when there are many traffic volumes, may offer an advantage in some cases, as long as the necessary work can be completed and the work site restored to essentially normal operating conditions to carry the higher traffic volumes during non-construction hours. In order for night work to provide a viable option, it is essential that the highway can easily be reconfigured from the normal traffic condition to the construction condition, and then returned to the normal condition before the morning peak period begins. If the construction operation must occupy the roadway for more than several hours each night, or if the temporary traffic pattern requires too great an effort to deploy and remove traffic control devices, no advantage is gained, and normally the night work option should not be considered further.

While the basic conditions discussed above must generally be satisfied for night work to provide a feasible traffic control option, there are a number of other factors that affect the feasibility and suitability of night work. Grouped into six major categories, these factors include the following (Bryden and Mace, 2003):

- Traffic: congestion, safety, and traffic control;
- Construction: productivity, quality, and two of the night-related factors (reduced visibility and greater difficulty communicating with supervisors and/or technical support staff);
- Social: factors affecting workers and factors affecting drivers such as disruption of normal sleep patterns, and normal family and social activity;
- Economic: construction costs, user costs, and accident costs;
- Environmental: air quality and fuel consumption; and
- Others: public relations, scheduling, lighting, availability of material, and labor.

There are some advantages or characteristics of nighttime work such as (Asim and Adeli, 2003):

- Benefits: reduce congestion, cooler temperature, longer allowable work “windows”, additional costs, and more difficult material supply logistics,
- Disadvantages: additional traffic control costs, noise, safety and health concern, and

- Difficulties: quality of work, availability of manpower, access to materials, and safety issues (impaired drivers, higher speeds, and low driver expectancy).

A.2.2 Comparison of Crashes during Night Time Work and Day Time Work

A.2.2.1 Occurrence of Crash

A study performed on several construction projects in California in the 1980s showed that crashes during night time work increased eighty-seven percents compared to those of day time work. Another study of night work lane closures in Virginia showed the increase of crashes during night time work. Ullman et al. (2004) showed that crashes during night time work were higher than those during day time work, as shown in Figure A-3.

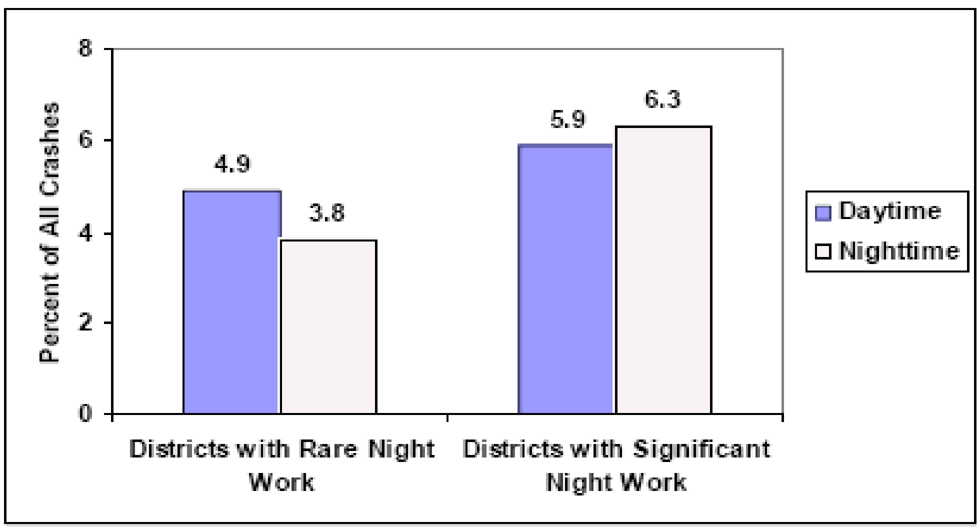

Figure A-3 Percent of Crashes Occurring in Work Zone (Ullman et al., 2004)

A.2.2.2 Crash Severity

Ullman et al. (2004) consolidated the crash data for all projects and computed the percent of crashes that were categorized as severe for this sample as a function of the night and day categories. As shown in Table A-5, the percent of crashes in the hybrid projects that were severe was slightly greater during the days of work activity as compared to the days of inactivity and to the before condition. At night, the percent of severe crashes was actually slightly less overall during the project on both nights of activity and nights without activity, as compared to the before condition. None of the differences are statistically significant.

Table A-5 Percent of Crashes That Are Severe at Project Locations

Project	Daytime			Nighttime		
	Before	During-Active	During-Inactive	Before	During-Active	During-Inactive
Hybrid	68.1	71.6	68.3	65.7	59.3	59.8
Resurfacing				58.9	70.5	41.6
Overall	68.1	71.6	68.3	65.4	59.9	59

A.2.2.3 Rear-end crashes

Ullman et al. (2004) assessed rear-end crashes for the seven work zone projects investigated. Several studies have consistently identified rear-end crashes as being overrepresented in work zones. These disproportionate increases in rear-end crashes are usually explained in terms of temporary disruptions in traffic flow for construction equipment and materials access, as well as congestion created by the reduction in available roadway capacity. The statistical analysis of rear-end crashes at the seven project locations combined are presented in Table A-6. At the project locations investigated, rear-end crashes as a percent of total crashes was only slightly higher during the day at the hybrid projects. Interestingly, it was during the days of inactivity that researchers saw the greater proportion of rear-end crashes.

Table A-6 Comparison of Rear-End Crash Frequencies at Project Locations

Project	Daytime			Nighttime		
	Before	During-Active	During-Inactive	Before	During-Active	During-Inactive
Hybrid	24.5	25.7	30.0	19.3	19.7	20.2
Resurfacing				10.6	31.5	8.5
Overall	24.5	25.7	30.0	18.9	20.2	19.6

A.2.3 Section Summary

Suitable options for night work must be able to carry the reduced nighttime traffic volume at an acceptable level of service, while permitting the roadway to be reconfigured to carry the higher daytime volumes. Options that may meet these requirements for night work include the following:

- Close lanes or shoulders during work hours.
- Shift traffic onto shoulders or temporary lanes adjacent to the permanent lanes.
- Shift traffic across the median, carrying both directions of travel on one roadway.
- Divert part of the traffic to alternate facilities, while carrying the remaining traffic through the project using the options listed above.
- Close the roadway through the project, detouring traffic to alternate or parallel routes or service-frontage roads.
- Divert through traffic, while permitting local traffic through the project, but restrict to fewer lanes.

Often, a combination of these options may be necessary to provide adequate contractor access to the roadway, while maintaining adequate traffic capacity. For example, it may be necessary to close the outside two lanes of a six-lane undivided highway for paving. Traffic on the opposing direction could be restricted to two lanes, while traffic on the affected direction is carried on the one remaining lane of that direction and one lane of the opposing side. A moveable traffic barrier may be added to separate the opposing traffic flows, depending on site considerations discussed in the design guidelines.

Some researches suggested that nighttime highway work can be performed safely and with economy & quality comparable to that performed in the daytime if the following conditions are prepared (Beacher et al., 2004):

- There is a need for a uniform national standard for highway work area illumination. AASHTO should consider developing this study based on the findings of a recommended illumination standard that could be adopted by its member states.

- There is a real need for improvements in manufacturer installed equipment lighting; AASHTO should encourage equipment manufacturers to offer appropriate nighttime operational lighting as optional equipment.
- The use of temporary roadway lighting may grow. The Roadway Lighting Committee of the Illuminating Engineering Society (IES) of North America should consider including a discussion of temporary roadway lighting.
- AASHTO or the FHWA should consider sponsoring the development of a basic course on Work Area Illumination: The course content could be used by SHAs as a basic training tool for their own personnel and for contractor personnel.

Also, other researchers identified seven strategies for improving traffic control for night work zones (Cottrell, 1999):

1) Improve the visibility of traffic control devices,
2) Improve the visibility of workers,
3) Improve the visibility of work vehicles,
4) Reduce speeding and increase driver attention,
5) Reduce glare from work lighting,
6) Manage queuing and traffic flow, and
7) Manage other safety risk factors.

A.3 Introduction of ITS for Improving Work Zone Safety

ITS technologies are increasingly applied to anticipate and mitigate congestion caused by highway work zones. These technologies provide ways to better monitor and manage traffic flow through work zones and increase safety for both workers and road users. By easing congestion and improving traffic flow, ITS technologies can help reduce user costs. ITS technologies also help improve incident detection, response, and clearance work in work zones, thus lessening user costs. This aspect is particularly important because traffic capacity is often reduced in work zones, and crashes in these areas cause even greater congestion and increase the potential for secondary crashes. Some applications of ITS technologies related to work zones are discussed in this section.

A.3.1 Case-Based Reasoning

Case-based reasoning (CBR) evolved from cognitive science research into an intelligent problem-solving approach that relies on previous experiences in the form of cases of previously solved similar problems.

Asim and Adeli (2003) used the CBR concept to manage work zone traffic flow. CBR is a multidisciplinary subject that is viewed from different perspectives in cognitive science, artificial intelligence, and knowledge engineering. It is loosely based on human reasoning and problem solving, which is essentially experiential and episode based. For example, an experienced traffic engineer can plan a work zone by recalling the knowledge gained from similar scenarios that he or she had solved previously, thus avoiding starting from scratch. CBR can be therefore thought of as a high level model of human reasoning and problem solving. Figure A-4 shows a case model for the CBR system in work zone traffic management.

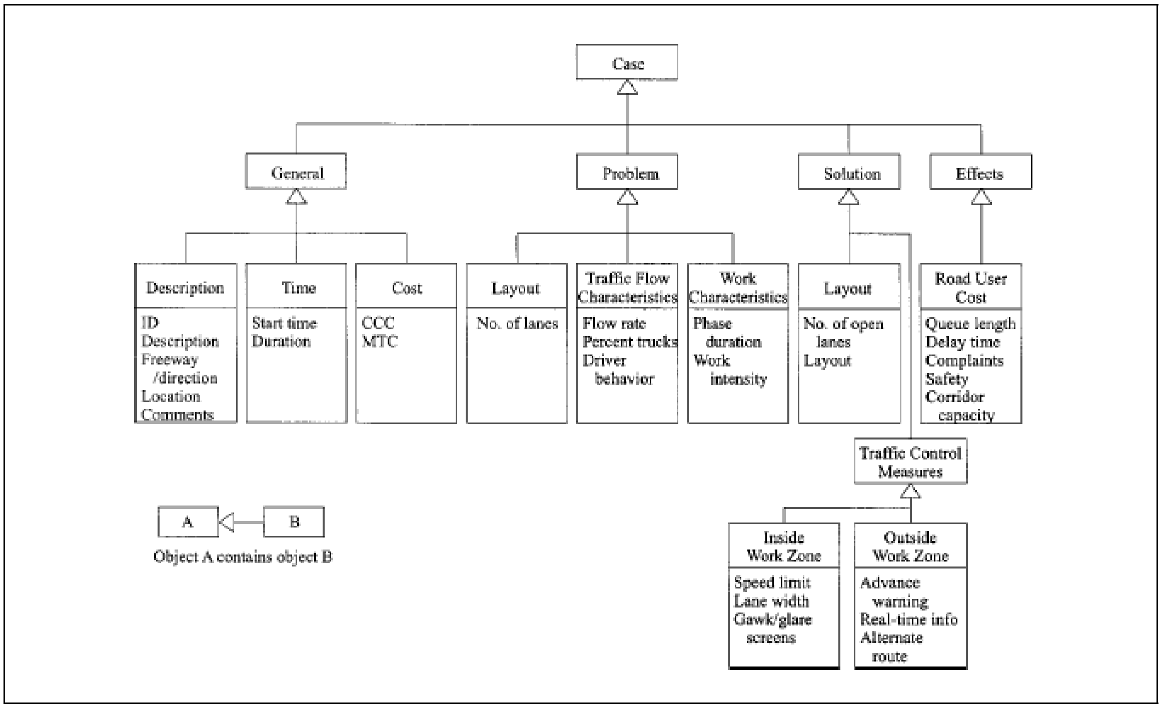

Figure A-4 Object-oriented Case Model for CBR System for Work Zone Traffic Management (Carlson et al., 2000)

A.3.2 Real Time Work Zone Traffic Control System

In order to reduce congestion and improve safety during reconstruction of the I-55 Lake Springfield Bridge in Illinois, an automated traffic information system was installed. Main components of real time traffic control systems (RTTCS) are Dynamic Message Signs (DMS), portable traffic sensors, portable CCTV (Closed-Circuit Television), and cameras linked via wireless communications to a central workstation. The operation concept of RTTCS is shown below Figure A-5. The effects of RTTCS are listed below (FHWA, 2004);

- The absence of severe congestion in the work zone,
- The absence of major accidents,
- A reduction in ticket-writing activities,
- Benefits and Impacts,
- Mobility,

- Safety, and
- Cost savings.

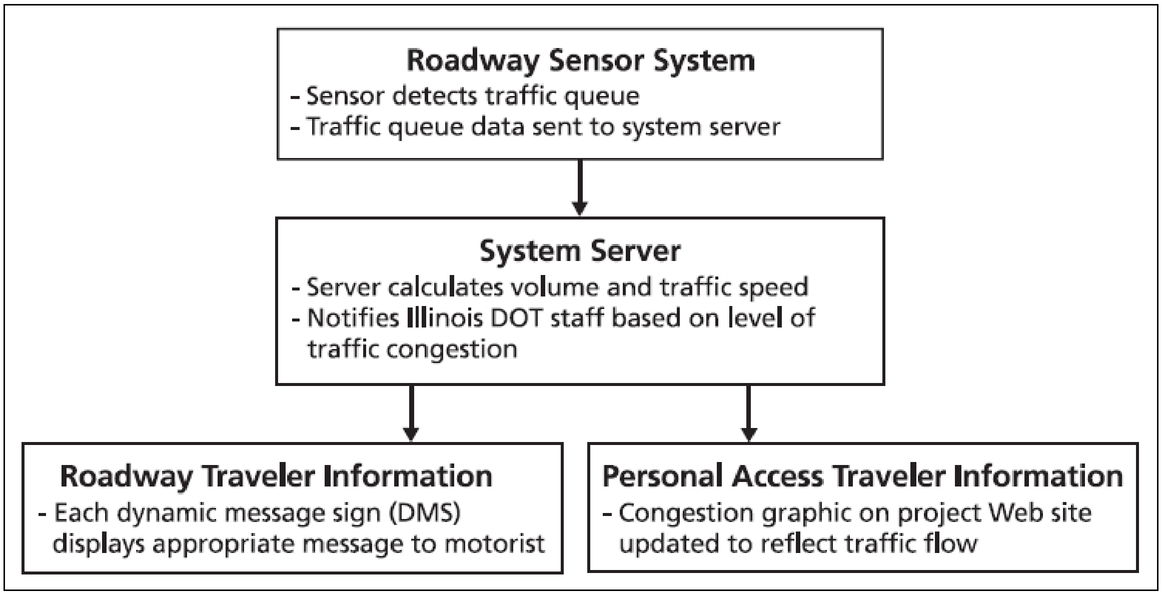

Figure A-5 Operation Concept of RTTCS (FHWA, 2004)

A.3.3 Work Zone Travel Time System

In order to reduce the congestion with the use of a traffic management contract incentive during the reconstruction of Arizona State Route 68, Arizona DOT used a work zone travel time system (FHWA, 2004). The work zone travel time system consisted of two monitoring stations and a central processor. Each monitoring station included an inductive loop embedded in the roadway, a control cabinet with a communications system, and two digital cameras (one for each direction of traffic) linked to the cabinet via fiber-optic cable. In addition, each camera was equipped with a light source to assist in reading license plates. The system required access to public utilities for a power source since power requirements for the lighting system made the use of solar power prohibitively expensive. Figure A-6 shows the operation procedures of the work zone travel time system. The benefits of this system are mobility and safety. The first benefit is mobility. The contractor responded to the travel time incentive/disincentive clause by limiting the number of flagging stations in the work zone and by limiting the duration of directional closings to two to three minutes at most. Both of these actions were taken to minimize the impact of the construction on motorists.

A secondary benefit was reduced exposure of workers to traffic. The contractor scheduled work to be performed in close proximity to travel lanes during periods of low traffic volume to minimize their disincentive fee.

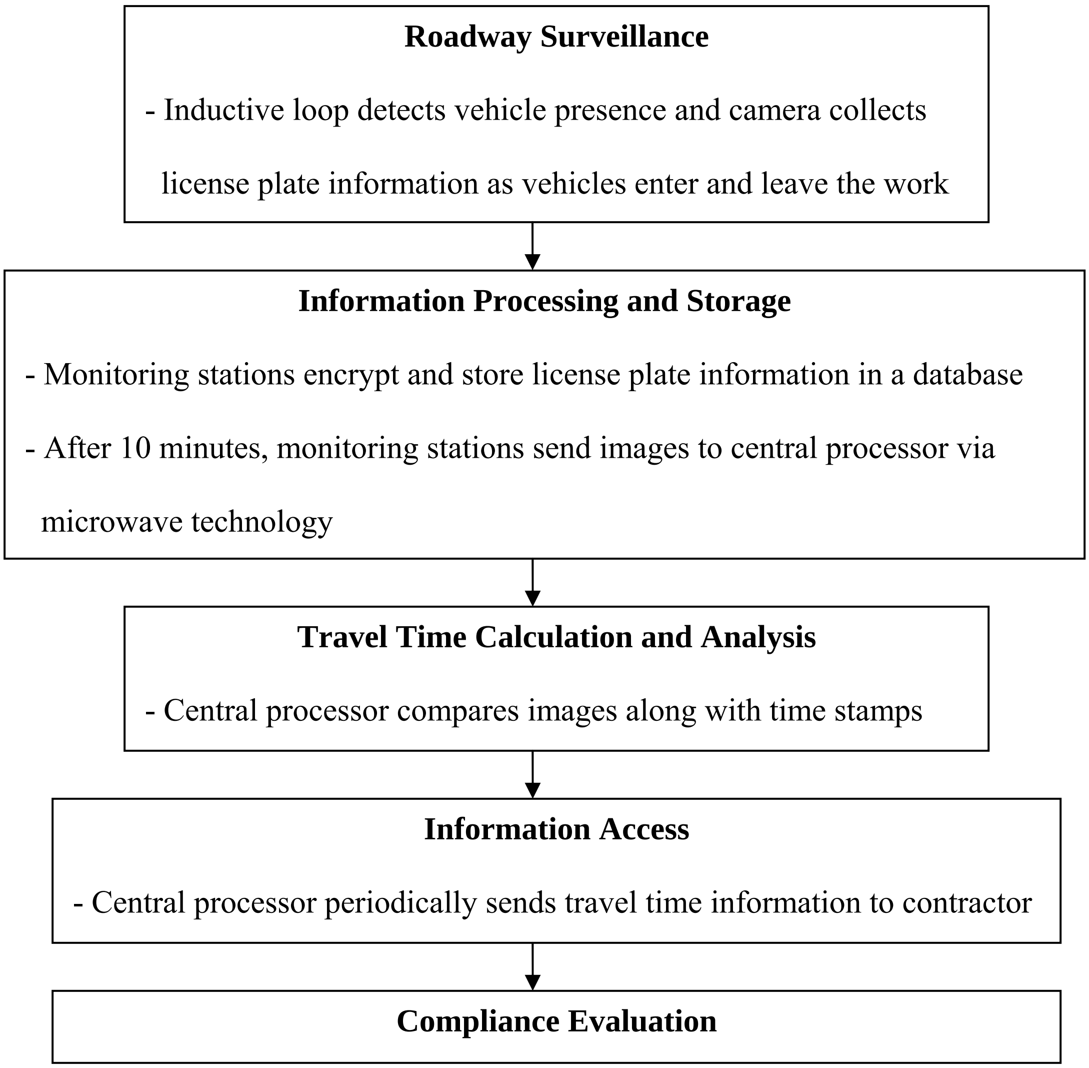

Figure A-6 Operation Procedures of Work Zone Travel Time System (FHWA, 2004)

A.3.4 Traffic Incident Management Programs for Work Zones

In order to ensure safe work zones and minimize the impact and delay to motorists, Colorado Department of Transportation (2003) used Traffic Incident

Management Programs for Work Zones. Planning for traffic incidents that occur within work zones is a critical component of reducing delay and increasing the safety and reliability of the highway system. Traffic incident management plans should be developed in a collaborative effort with the emergency response and public safety community and incorporated in the overall work zone management plan. The level of complexity of these plans should reflect the duration and complexity of the construction project and its impacts on the system. Traffic incident management programs address several key components or phases of traffic incident management, including:

- Incident detection and verification,
- Incident response,
- Incident site management,
- Incident clearance, and
- Motorist information dissemination

A.3.5 Section Summary

Many new transportation technologies including ITS have been applied in highway work zones. The CBR system, the real time work zone traffic control system, the work zone travel time system, and traffic incident management programs for work zones were a few ITS technologies applied to work zones. In order to better monitor and manage traffic flow through work zones and improve safety for workers and motorists, proactive uses of ITS advanced technologies are recommended.

Appendix B: Interview Format

1. Project Outline

1.1 **Project Name**

1.2 **Project Location (route number, mile post, city or county name)**

Route Number	Mile Post (Intersection Name)	City or County name
	From: To:	

1.3 **Road Type**

Road Type	Area	Horizontal Alignment	Vertical Alignment	# of Intersections	Others
Freeway Arterial	Urbanized Area Suburban area Rural Area	Straight Curve Others ( )	Level Grade Rolling Mountain Others ( )		

1.4 **Project Duration**

Starting Date (Month/Day/year) (Time If possible)	Ending Date (Month/Day/year) (Time If possible)

1.5 **Project Executor**

	Name	Title	Department	Company (Organ)
Senior Director				
Director				
Resident Engineer				
Traffic Engineer for Traffic Control				

1.6 **Project Manager (region)**

	Name	Title	Department	Company (Organ)
Project manager				

1.7 **Total Cost: Construction Cost, WZ Traffic Control Cost**

Total Cost	Construction Cost	WZ Traffic Control cost
K$	K$	K$

2. Construction Type and Cost

2.1 Construction Type (Detailed construction type)

Construction Type	**Reconstruction, Rehabilitation, Repair, Maintenance,** **Others ( )**
Detailed Construction Contents	**Overlay, Widening, Shoulder,** **Others ( )**

2.2 Construction Scale (Partial Closure, Full Closure, No closing, etc)

		Where	**When**	**How long (Time)**	**How many (Lanes)**	**Others**
Full Closure	**1st**					
	2nd					
	3rd					
Partial Closure	**1st**					
	2nd					
	3rd					
Others						

2.3 Road Component

Main Lane (Through lane)	**1st lane, 2nd lane, 3rd lane, HOV lane** **others ( )**
Turning lane	**Left, Right, U-turn**
Roadsides	**Lateral Clearance, Roadside, Shoulder,**
Others	

2.4 Main Construction Time (detail)

	Weekday / Weekend	Peak / Non-peak	Day/Night
Details	**From:** **To:**	**From:** **To:**	**From:** **To:**

2.5 Construction Phases

Phases	Time	Main Construction	WZ Speed Limit	Regular Speed Limit	Others
Phase I	**From** **To**				
Phase II	**From** **To**				
Phase III	**From** **To**				
Phase IV	**From** **To**				
Others					

2.6 Construction Cost Categories

Direct Construction Cost	Labor Cost	Traffic Control Cost			Interests	Others
		Roadway	Structure	Signing		

2.7 Man-Power (workers)

Total	Number /Phase	Number / Time	Average Working Time	Others

3. Traffic Control Plans and Devices

3.1 Traffic Control Plans by Phase or Time

Phases	Main Traffic Control type (Type, Qty)	Minor Traffic Control type (Type, Qty)	Traffic Control Cost	Others
Phase I				
Phase II				
Phase III				
Phase IV				
Others				

3.2 Advertisement of Traffic Control Plan (WZ)

Method	VMS	Mobile	TV	Radio	Pamphlet	Web-site	Others
When							
How long							
Driver Responses							

3.3 Traffic Control Devices and Types

	Advanced Warning Area	Transition Area	Activity Area (Construction Area)	Termination Area
Type				
Quantity				
Length				
Cost				
Setting Time				
Removal Time				
Effect				
Others				

3.5 Protection Trucks / Patrol car with Attenuators

	Truck	Patrol car	Others
Where		Stationary ( ) Cruising	
When			
How long			
How often			
Driver Responses			

3.6 Other Special Traffic Control Devices and Measures for safety

Types	
Where	
When	
How long	

4. Traffic Condition Before and During Construction

4.1 Speed Difference

	Before		After	
Speed Limit				
Speed Control Method				
	Yes, No	Quantity	Location	Others
Regulatory Sign				
Advisory Sign				

4.2 Other Traffic Condition

Traffic Condition	Drivers Responses	
	Before	During
Speed		
Traffic Volume		
Delay		
Travel Time		
Special Driver Behavior		
Others		

5. Crash History during Construction

5.1 Case 1

	Contents	
Crash Types		
Crash Severity		
Location		
When		
Time	Working	No working
	Day	Night
Road Surface Condition	Wet, Dry, Others ( )	
Weather	Clear, Rain, Snow, Cloudy, Fog, Others ( )	
Number of Vehicles		
Vehicle real speed		
Related with WZ (construction)		
Related with Workers		
Police Survey and Record	Yes	No
Description		
Others		

5.2 Case 2

	Contents
Crash Types	
Crash Severity	
Location	
When	
Time	Working No working
	Day Night
Road Surface Condition	Wet, Dry, Others ( )
Weather	Clear, Rain, Snow, Cloudy, Fog, Others ( )
Number of Vehicles	
Vehicle real speed	
Related with WZ (construction)	
Related with Workers	
Police Survey and Record	Yes No
Description	
Others	

6. Others

Items		Contents
Construction Diary	Presence	Yes, No
	Copy	Yes, No
Special Memos		Yes, No
Original Data		Region Office, Archive
Special Advice and recommendation for WZ Safety		
Special Memos		

\- Great Thank for Your Help -

Appendix C: Results of Detailed Analysis of Two Case Studies

C.1 Case I: US-6 from 196.79 MP to 200.51 MP

C.1.1 General Analysis

C.1.1.1 Spatial and Temporal Crash Analysis

In order to find out the spatial and temporal characteristics of crashes, the crashes within 5 miles upstream and downstream of the work zone were analyzed. Crash rates per 100 MVMT by severity were determined for time and space. Figure C-1 shows the spatial and temporal trend by severity. These crash rates were computed for each 1 mile section. For instance, 'west 4 mile' means the fourth one mile section from the west end of the work zone.

As shown in Figure C-1, the highest 'no injury' crash rate, 404.30 crashes per 100 MVMT, resulted in the west 5 mile section in the 'after' construction period. Actually, the crash data showed that 'no injury' crash rate increased from the 'before' period to the 'during' period. Then, it sharply increased in the 'after' period. Note that the 'Possible injury' crash rate also increased significantly. As for fatal crashes, the 'east 1 mile' section had a higher fatal crash rate. Thus, fatal crashes may be attributable to the work zone. Also, the 'west 1 mile' section during the construction period had the highest rate, much larger than the fatal crash rate in the work zone during the construction period.

As for the relationship between crash severity and construction time, the highest fatal crash rate occurred in the 'west 4 mile' before construction, in the 'west 1 mile' during construction, and in the 'eastbound 1 mile' after construction. Even though the crash severity became less severe in the work zone after construction, it increased in the other zones.

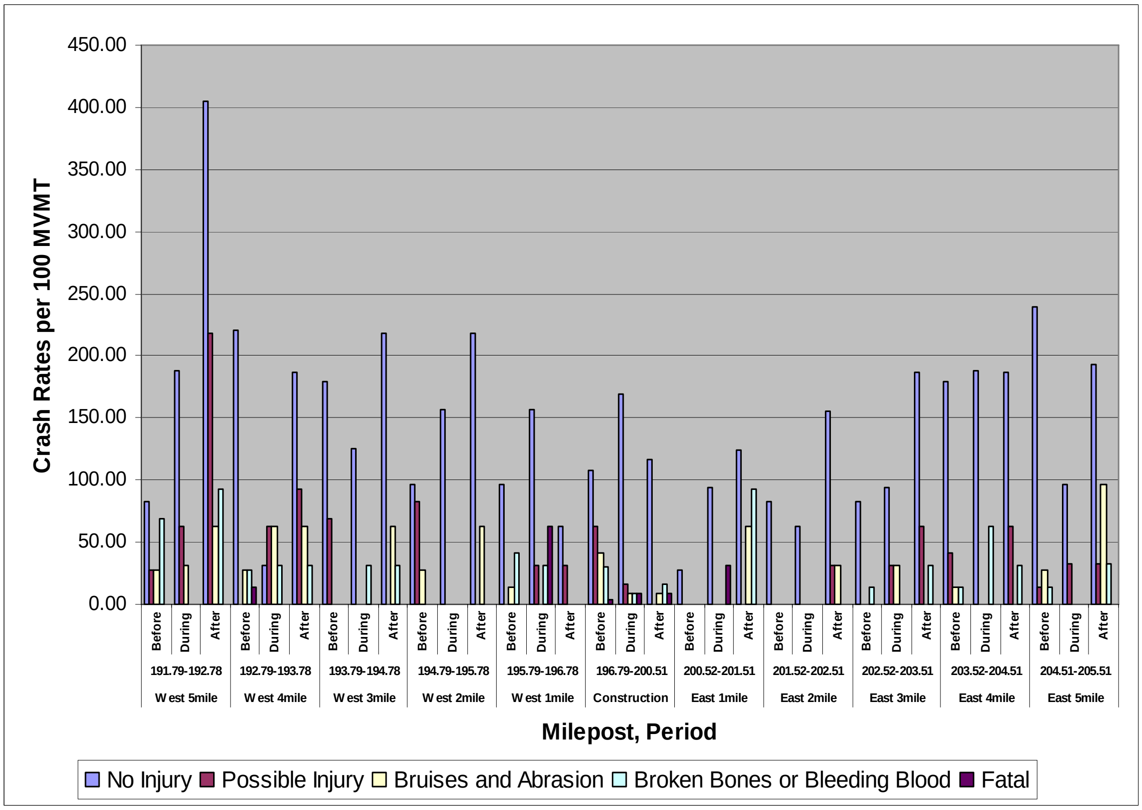

Figure C-1 Spatial and Temporal Crash Rate by Severity (US-6 Study Site)

Figure C-2 compares the spatial and temporal crash rates by milepost in the work zone. The highest crash rate section was the one mile section between milepost 197.0 and 198.0 through the three data analysis period. As shown in Figure C-2, crash rates between milepost 197.0 and 198.0 increased after construction from 77.83 per 100 MVMT to 111.51 per 100 MVMT because that section didn't have any changes in horizontal and vertical alignment even after construction. During construction, crash rates were lower in all sections than those before construction.

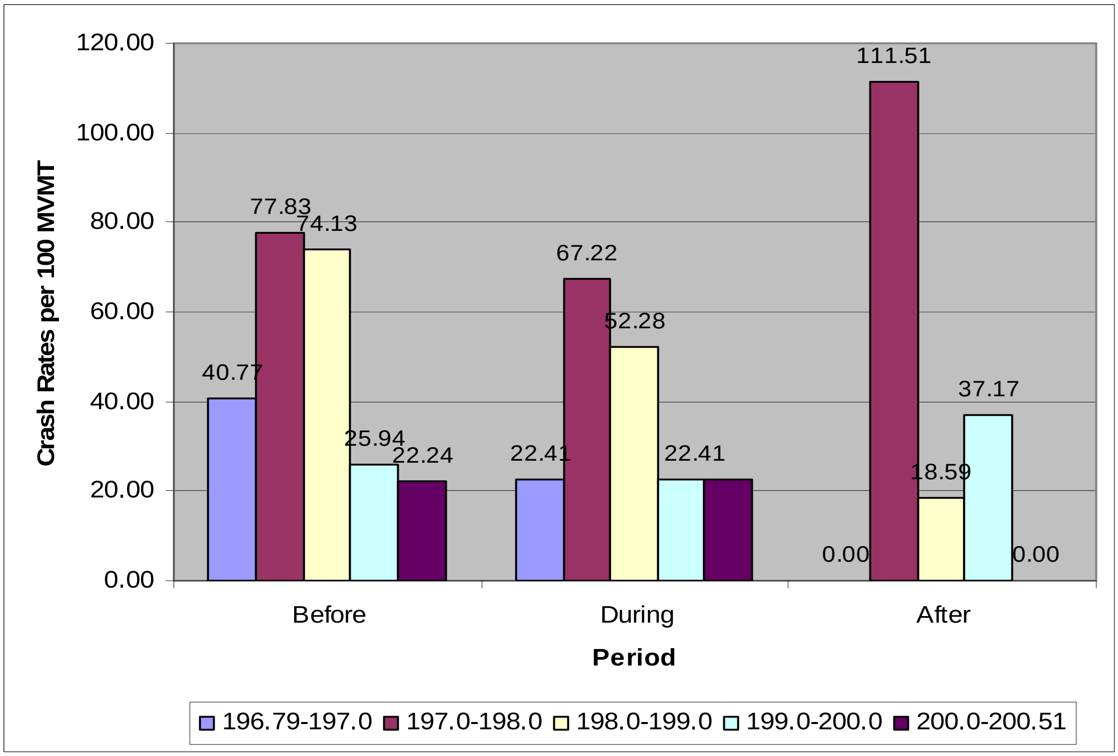

Figure C-2 Spatial and Temporal Crash Rate Comparison by Milepost in Work Zone (US-6 Study Site)

Figure C-3 shows monthly crash rates during construction. April of 2000, April of 2003 and May of 2003 had the highest crash rate of 25.30 per 100 MVMT during construction. Phase I of the construction began in April of 2002, Phase II in May of 2003 and Phase III in June of 2003. These may have contributed to these high crash rates. There were no crashes in July of 2002 and 2003 and January of 2003 and June of 2003.

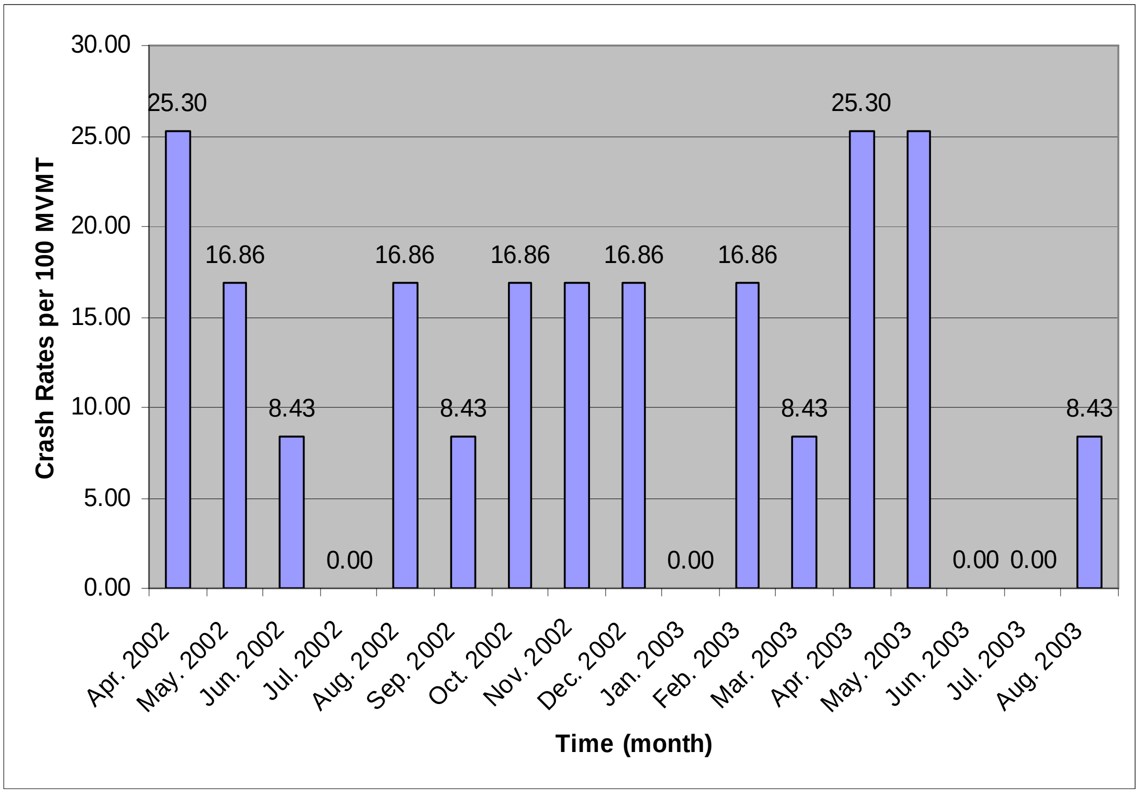

Figure C-3 Monthly Crash Rate during Construction (US-6 Study Site)

C.1.1.2 Other Analyses

Table C-1 shows crash rates in 100 MVMT by severity and by light condition. The 'dark street or highway not lighted' condition had the highest crash rate, 152.48 crashes per 100 MVMT followed by the 'daylight' condition, 108.92 crashes per 100 MVMT. All fatal crashes occurred in the 'dark street or highway not lighted' condition during construction.

The majority of crashes that took place during construction in the work zone were 'no injury' crashes as shown in Table C-1.

Table C-1 Crash Rates by Severity and Light Condition (US-6 Study Site)

(Unit: Crashes per 100 MVMT)

	No Injury	Possible Injury	Bruises and Abrasion	Broken Bones or Bleeding Blood	Fatal	Total
Daylight	98.02	0.00	0.00	10.89	0.00	108.92
Dark Street or Highway, Lighted	0.00	0.00	0.00	0.00	0.00	0.00
Dark Street or Highway, Not Lighted	119.81	10.89	10.89	0.00	10.89	152.48
Dawn	0.00	0.00	0.00	0.00	0.00	0.00
Dusk	0.00	10.89	0.00	0.00	0.00	10.89
Total	217.83	21.78	10.89	10.89	10.89	272.29

Figure C-4 shows crash rates by analysis period and traffic control where crashes took place. Crash rates were the highest for the "traffic lanes marked" category in all three analysis periods, before, during, and after construction. A few crashes took place in the 'officer or watchman' and 'slow or warning sign' condition in 'before' and 'after' construction periods. During construction, there were some crashes recorded under the 'no passing lanes', which means essentially that crashes took places in the work zone.

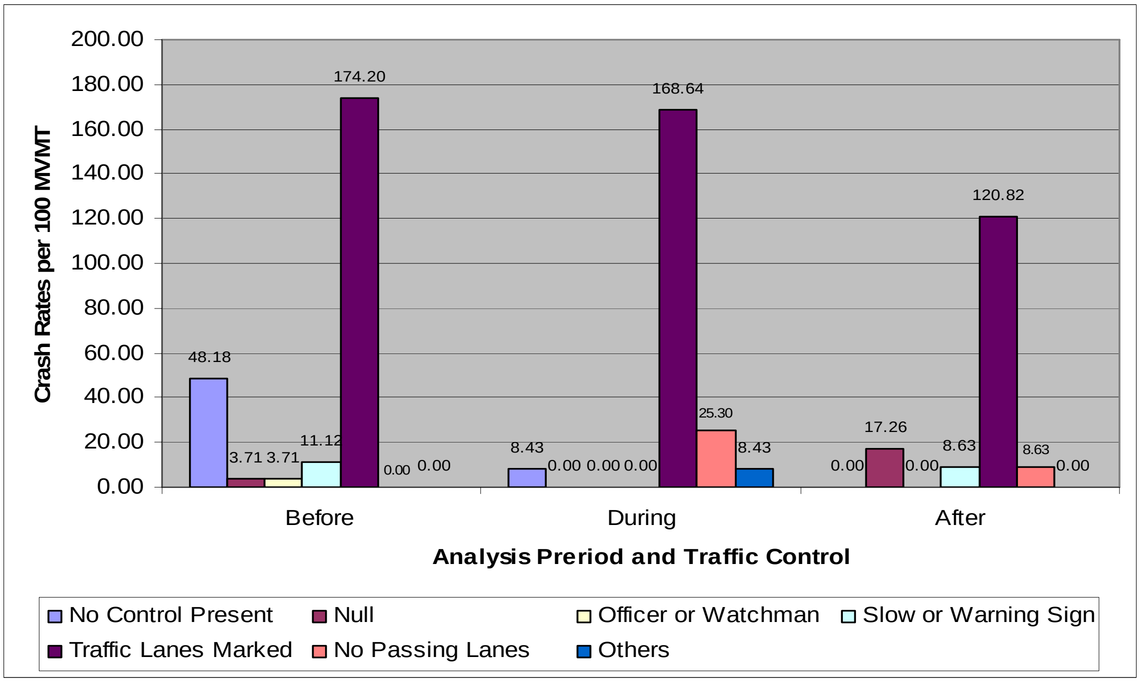

Figure C-4 Crash Rates by Analysis Period and Traffic Control (US-6 Study Site)

Figure C-5 shows crash rates by alignment for each analysis period. The highest crash rates were recorded in the 'curve grade' section before, during and after construction. While crash rates for the 'curve grade' and 'grade straight' sections during and after construction decreased, crash rates in the other alignment sections increased both during and after construction. Especially, crash rates for the 'curve hillcrest' section during construction were higher than those for the 'curve hillcrest' section before and after construction. After construction, crashes took place in a new alignment section named 'curve level'.

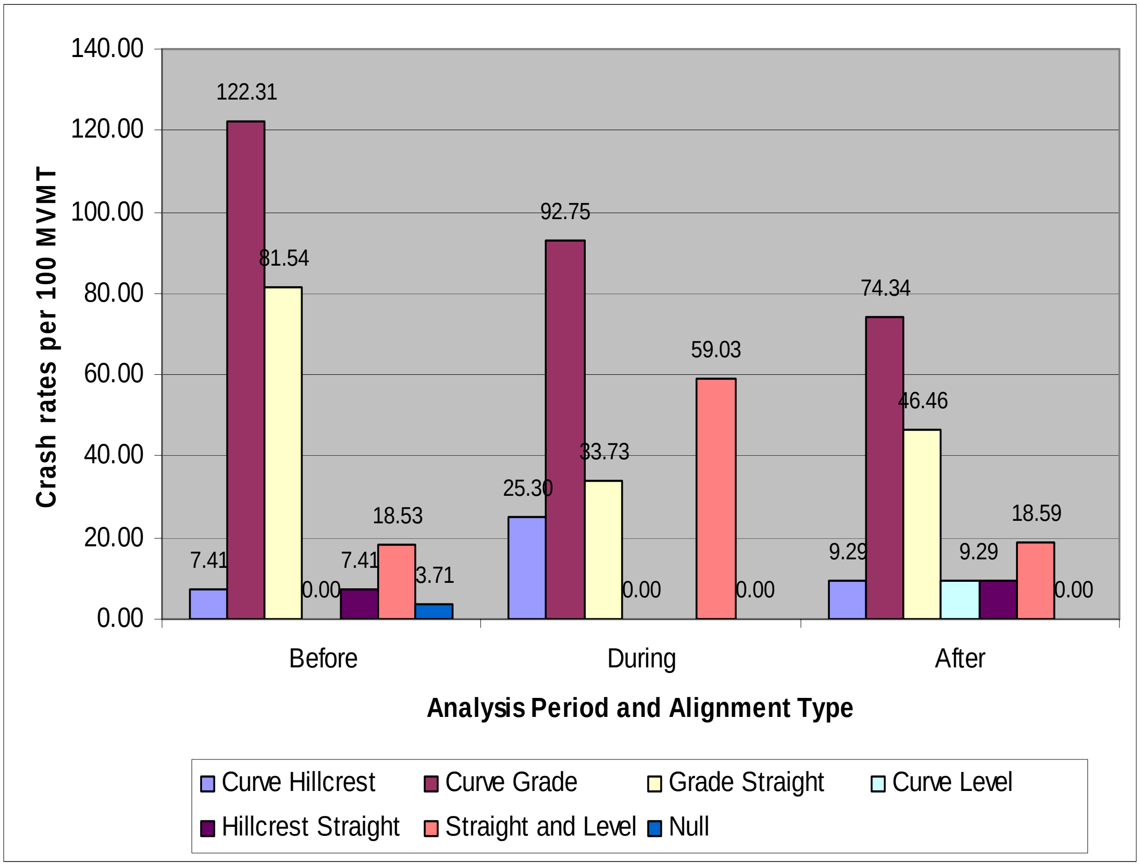

Figure C-5 Crash Rates by Analysis Period and Alignment (US-6 Study Site)

Table C-2 presents crash rates by weather condition. Most crashes, 82 percent of the total number of crashes in the work zone, happened in the ‘clear’ and ‘snow’ weather conditions. The crash rate in the ‘cloudy’ condition was higher during construction than before and after construction. The total crash rate for before construction was higher than during and after construction, the rate for after construction being the lowest, which means that work was beneficial for improving traffic safety in this stretch of highway.

Table C-2 Crash Rates by Analysis Period and Weather Condition (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	Before	During	After
Clear	103.78	84.32	83.63
Cloudy	14.83	50.59	18.59
Fog	7.41	0.00	0.00
Raining	0.00	0.00	9.29
Snowing	107.48	75.89	55.76
Windstorm	3.71	0.00	0.00
Null	3.71	0.00	0.00
Total	240.91	210.80	167.27

Figure C-6 shows crash rates in the work zone by weather condition during construction, while Table C-2 describes three periods, before, during, and after construction. The 'clear' condition had the highest crash rates, 84.32 crashes per 100 MVMT. The other conditions followed by 'snowing' and 'cloudy', 75.89 crashes per 100 MVMT and 50.59 crashes per 100 MVMT, respectively.

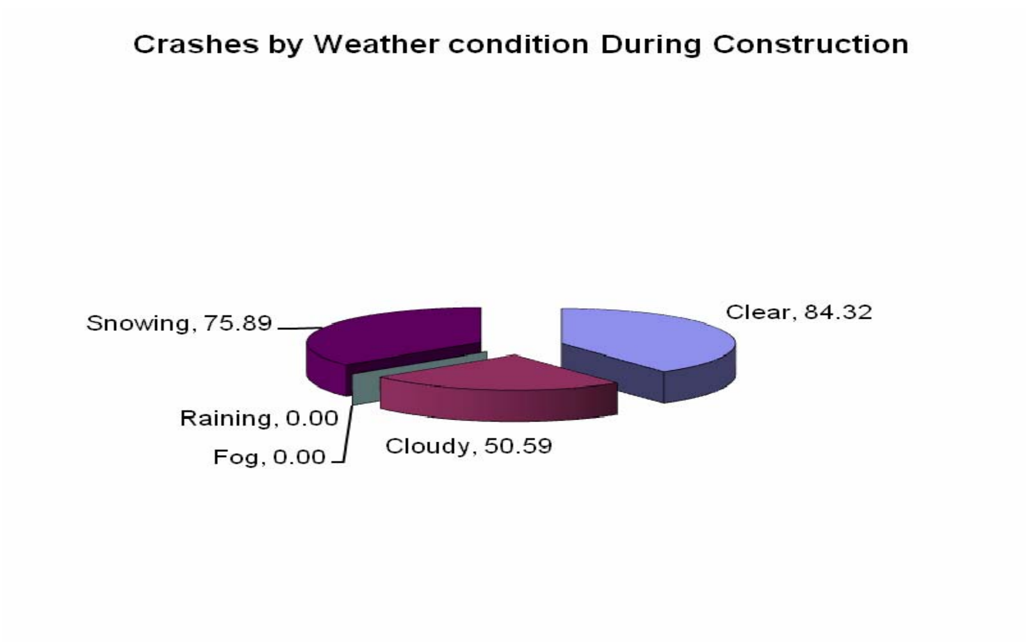

Figure C-6 Crash Rates by Weather Condition during Construction (US-6 Study Site)

Figure C-7 shows crash rates by analysis period and surface condition. Almost one half of all crashes happened on the 'dry' surface condition, and crash rates of all surface condition decreased as time passed except on the 'wet' surface condition.

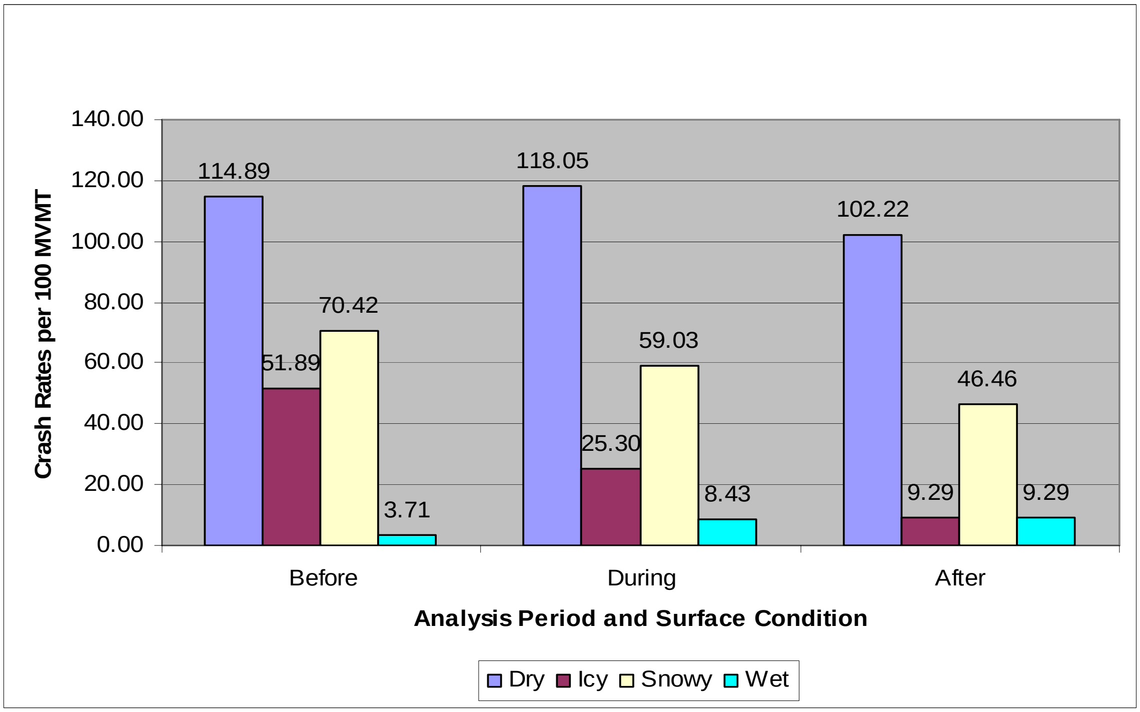

Figure C-7 Crash Rates by Analysis and Surface Condition (US-6 Study Site)

Table C-3 shows crash rates by vehicle involvement. Crashes by vehicle involvement were divided into two groups, single vehicle and multi-vehicles (MV-MV). About 80 percents of crashes were related to 'single vehicle'. The crash rates, 24.0 percents, related with multi-vehicles during construction were higher than before and after construction.

Table C-3 Crash Rates by Analysis Period and Vehicle Involvement (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	Before	During	After
MV-MV	51.89	50.59	27.88
Single vehicle	189.02	160.21	139.39
Total	240.91	210.80	167.27

Table C-4 shows the number of crashes by crash type during construction in the work zone. Thirty six percent of crashes were related to the 'MV-Wild Animal' crash type. Some accident types like 'ran off roadway-right (MV-Fixed Object)' and 'MV-MV' together resulted in 36 percent of the total number of crashes. All other crash types had only one case during construction.

Table C-4 Number of Crashes by Crash Types during Construction (US-6 Study Site)

Number of Vehicle	Crash Type	Number of Crashes
Single Vehicle	MV-Animal(Wild)	9
	MV-Fixed Object (MV-Other Object)	1
	MV-Fixed Object (Overturned)	1
	MV-Other Object	1
	Ran Off Roadway-Left	1
	Ran Off Roadway-Left (MV-Fixed Object)	1
	Ran Off Roadway-Right (MV-Fixed Object)	1
	Ran Off Roadway-Right (Overturned)	4
MV-MV	MV-MV	5
	MV-MV(Ran Off Roadway-Right)	1
	Total	25

C.1.2 Directional Analysis

C.1.2.1 Outline

Over two-thirds of work zone crashes at the US-6 study site took place in the 'westbound' direction for the three analysis periods, before, during and after construction. During construction, the crash rates of the 'westbound' and the 'eastbound' directions were 119.5 crashes per 100 MVMT and 59.75 crashes per 100 MVMT, respectively. After construction, the crash occurrences in the 'westbound' direction, accounted for 78.5 percents of the total, much more than before and during construction.

Table 4-6 shows a summary of directional crashes. Crashes in the 'northbound' direction were excluded from detailed directional analyses because the number of crashes was small for the three analysis periods and the occurrences of such crashes were limited to special periods, before, and after. Also, the analysis periods of before, during, and after construction are the same as those of the total crash for 3 years, 17.5 months, and 16.5 months, respectively, as discussed in C.1.1.

Table C-5 Summary of Directional Crashes (US-6 Study Site)

	Before			During			After		
	Number of Crashes	Annual average	Crash Rates per 100 MVMT	Number of Crashes	Annual average	Crash Rates per 100 MVMT	Number of Crashes	Annual average	Crash Rates per 100 MVMT
Eastbound	26	8.67	96.36	8	5.49	59.75	4	3	33.44
Westbound	38	12.67	140.84	16	10.97	119.5	14	10.5	122.3
Northbound	1	0.33	3.71	1	0.69	7.47	0	0	0
Total	65	21.67	240.91	25	17.15	186.72	18	13.5	155.74

C.1.2.2 Spatial and Temporal Crash Analysis

Figure C-8 shows spatial and temporal crash distribution of crash data by direction and analysis period. The section between milepost 197.00 and 198.00, except the eastbound direction before construction, had the highest crash rates in this work zone. In the eastbound direction, crashes disappeared at all sections after construction except the section between milepost 197.0 and 198.0. This indicates that traffic safety conditions were generally improved by this work except the section between milepost 197.0 and 198.0.

Like in the eastbound direction, crash rates decreased in all sections in the westbound direction except two sections between milepost 197.0 to 198.0 and milepost 199.0 to 200.0. Another observation is that crash rates were lower at both ends of work zone than those in the mid-section of the work zone.

Traffic safety conditions of the section between milepost 197.0 and 198.0 in both directions were worse after construction. Traffic safety conditions of the eastbound direction after construction was much better than those of the westbound direction.

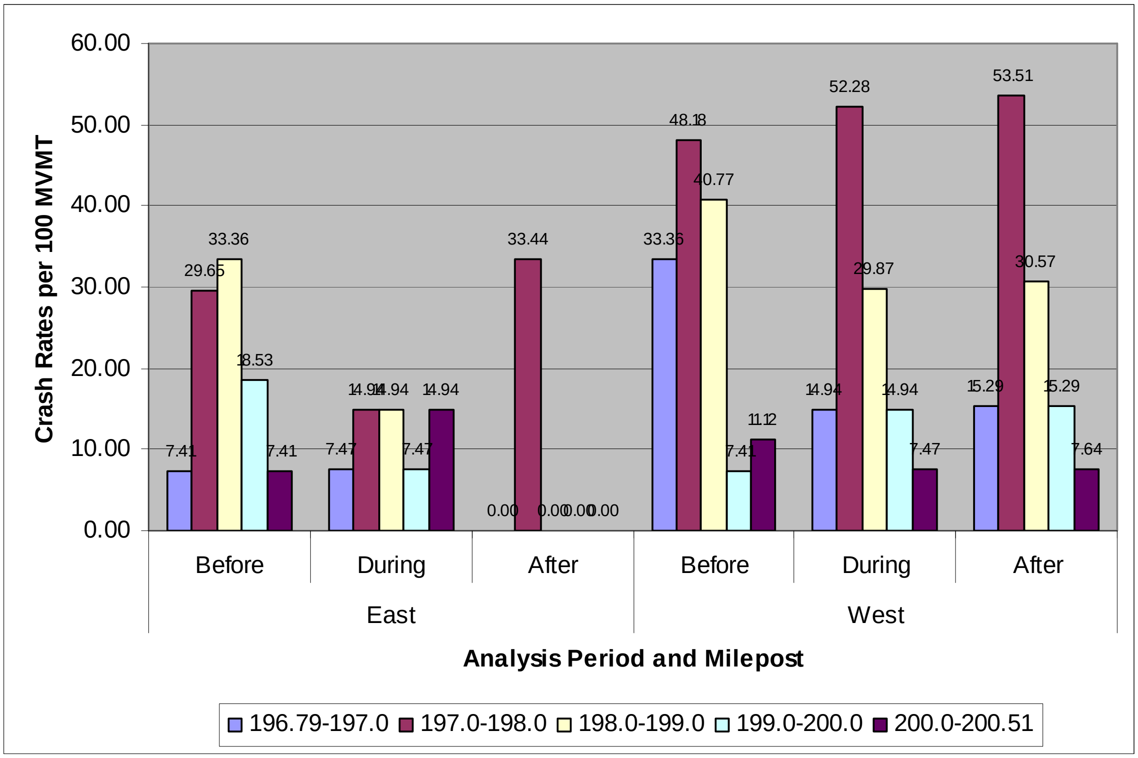

Figure C-8 Spatial and Temporal Distribution of Crash Rates by Direction and Analysis Period (US-6 Study Site)

As shown in Figure C-9, the westbound direction had higher crash rates than the eastbound direction. Therefore, it is concluded that the westbound direction was more dangerous than the eastbound direction. Even though severe crashes like 'broken bones or bleeding blood' and 'fatal' crashes disappeared in the eastbound direction after construction, rates of severe crashes (the sum of crash rates of 'broken bones or bleeding blood' and 'fatal' crashes) in the westbound direction actually increased from 18.54 crashes per 100 MVMT to 25.08 crashes per 100 MVMT.

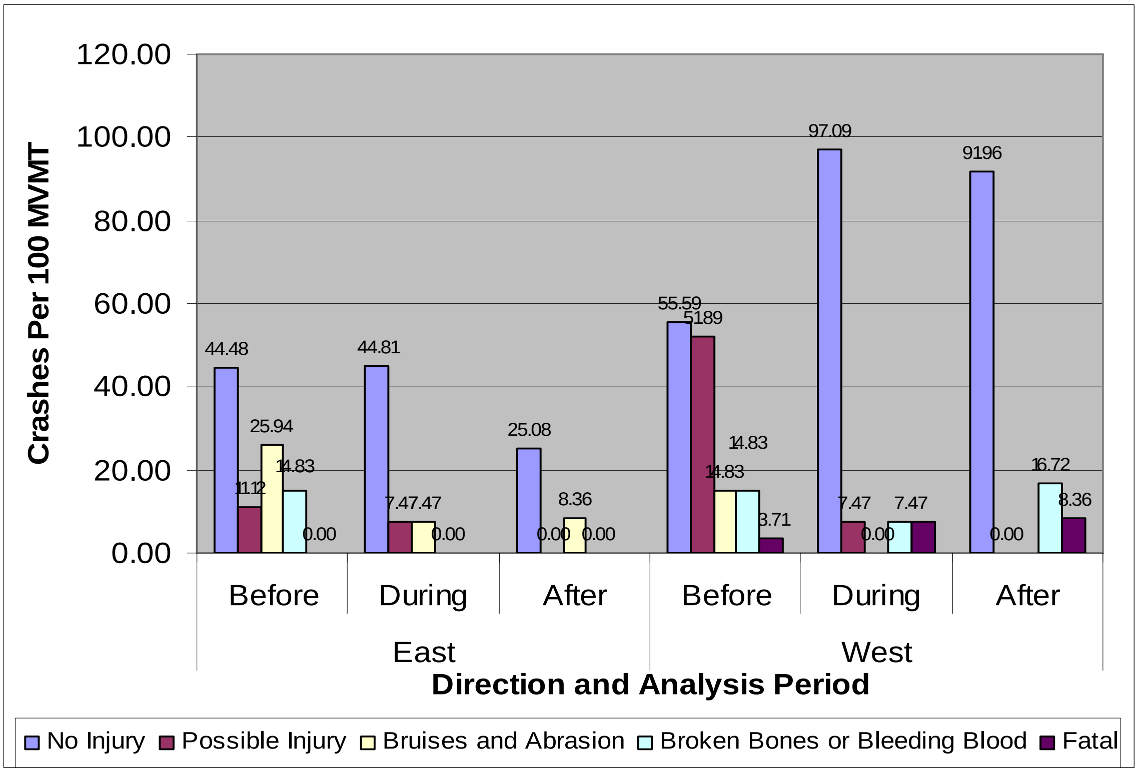

Figure C-9 Directional Distribution of Crash Rates by Analysis Period and Severity (US-6 Study Site)

Figure C-10 shows monthly crash rates distribution by direction. This figure shows large differences in the number of crashes by month between the two directions, as shown in Table C-5. While the crash rates in the eastbound direction were distributed in April, September, October, November, and December of 2002 and in May of 2003, those in the westbound direction were distributed through the whole analysis period except the month of June.

The highest crash rates in the eastbound direction happened in April of 2003 and the highest crash rates in the westbound direction took place in April and May of 2002, and February and April of 2003. In both directions, crash rates in the summer season from June to August of 2002 were the lowest.

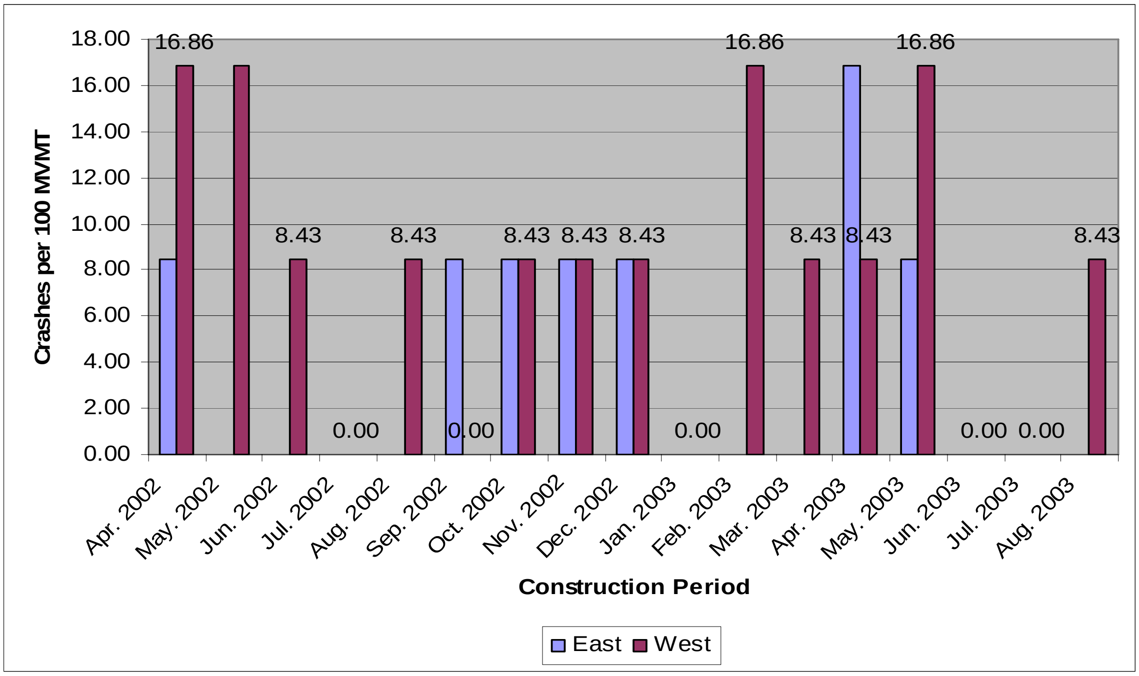

Figure C-10 Monthly Crash Rate Distribution by Direction during Construction (US-6 Study Site)

Table C-6 shows crash rates by severity and light condition. Most of the crashes happened in the 'daylight' and 'dark street or highway not lighted' conditions. Severe crashes intensively happened on the 'daylight' and 'dark street or highway not lighted' in the westbound direction.

Table C-6 Directional Crash Rates by Severity and Light Condition (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	No Injury			Possible Injury		Bruises and Abrasion		Broken Bones or Bleeding Blood		Fatal		Total
Direction	East	West	North	East	West	East	West	East	West	East	West	
Daylight	7.47	52.28	7.47	0.00	0.00	0.00	0.00	0.00	7.47	0.00	0.00	74.68
Dark Street or Highway Lighted	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dark Street or Highway Not Lighted	37.34	44.81	0.00	7.47	0.00	7.47	0.00	0.00	0.00	0.00	7.47	104.56
Dawn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dusk	0.00	0.00	0.00	0.00	7.47	0.00	0.00	0.00	0.00	0.00	0.00	7.47
Total	44.81	97.09	7.47	7.47	7.47	7.47	0.00	0.00	7.47	0.00	7.47	186.71

Figure C-11 shows directional crash rate distribution by traffic control type and analysis period. In both directions, there were high crash rates in the 'traffic lanes marked' type except during construction in the westbound direction. Also, both directions during the construction have 'no passing lanes' as a traffic control type, which means that crashes took place in the work zone. What stands out in this figure is that the 'no control present' type had the highest crash rate during construction in the westbound direction.

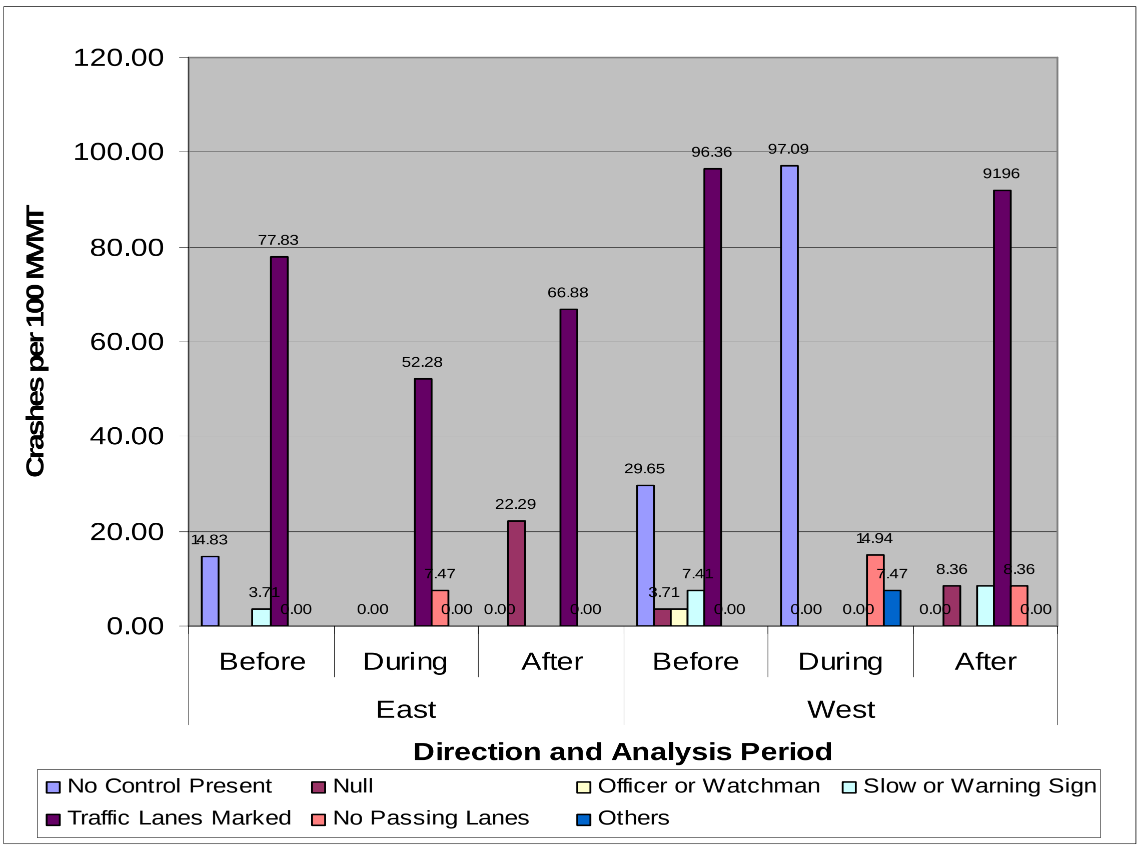

Figure C-11 Directional Crash Rate Distribution by Traffic Control Type and Analysis Period (US-6 Study Site)

Figure C-12 shows directional distribution of crashes in percentage by day of the week and analysis period. Crash occurrences by day of the week were similar to those in both directions except in the eastbound direction after construction.

In the eastbound direction, the percent share of Sunday increased dramatically after construction. There were no crashes on Sundays during construction.

In the westbound direction, the crash occurrence trend seemed to have changed from a spread-out distribution of crashes before construction to a higher concentration in mid-week days after construction. What's interesting is that there were no crashes on Mondays during construction in the westbound direction.

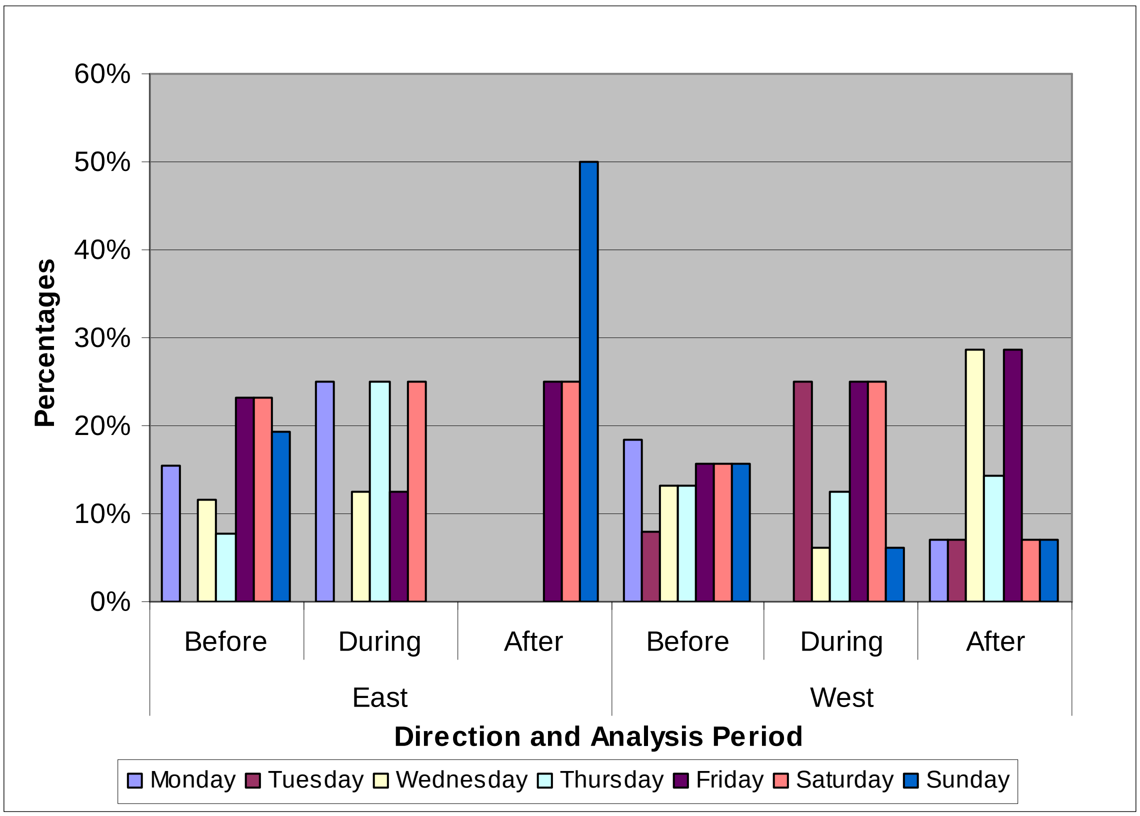

Figure C-12 Directional Distribution of Crashes in Percentage by Day of the Week and Analysis Period (US-6 Study Site)

Figure C-13 shows directional distribution of crashes by alignment type and analysis period. Generally, there were severe safety problems in the 'curve grade' and 'grade straight' sections. The highest crash rate in the 'curve grade' section occurred in the eastbound direction except during construction. Crash rates of 'straight and level' during construction in both directions increased. Crash rates in all alignment conditions in both directions decreased after construction except after construction in the westbound direction. In the westbound direction, alignments might have gotten worse after construction because new crashes in the other alignment types such as 'curve level' and 'hillcrest straight' took place.

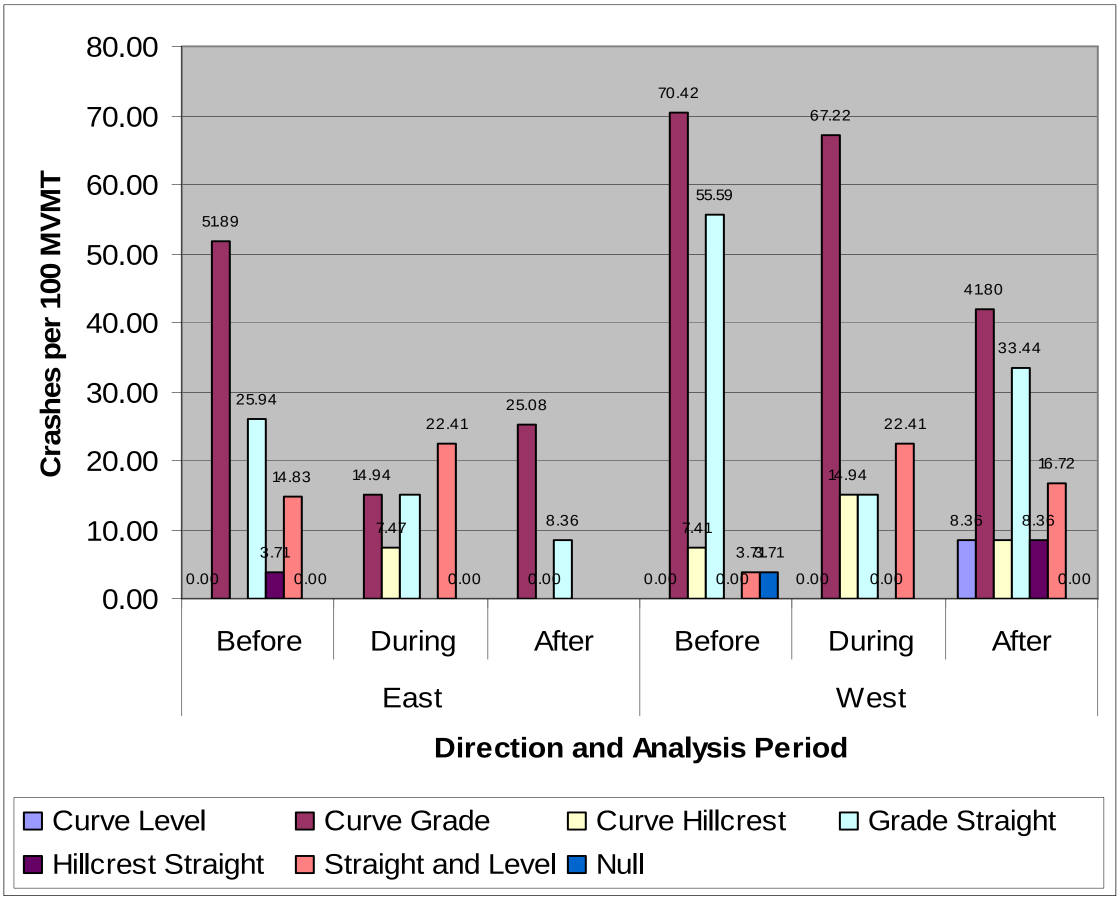

Figure C-13 Directional Distribution of Crashes by Alignment and Analysis Period (US-6 Study Site)

Figure C-14 shows directional distribution of crash rates by weather condition and analysis period. High crash rates happened in the 'clear' and 'snowing' weather conditions. In the eastbound direction, crash rates were higher in the 'clear' and 'snowing' weather conditions than other weather conditions. In the westbound direction, similar trends happened with an addition of the 'cloudy' condition that had the same crash rate as that in the 'clear' condition. Overall, crash rates in the westbound direction were higher than those in the eastbound direction.

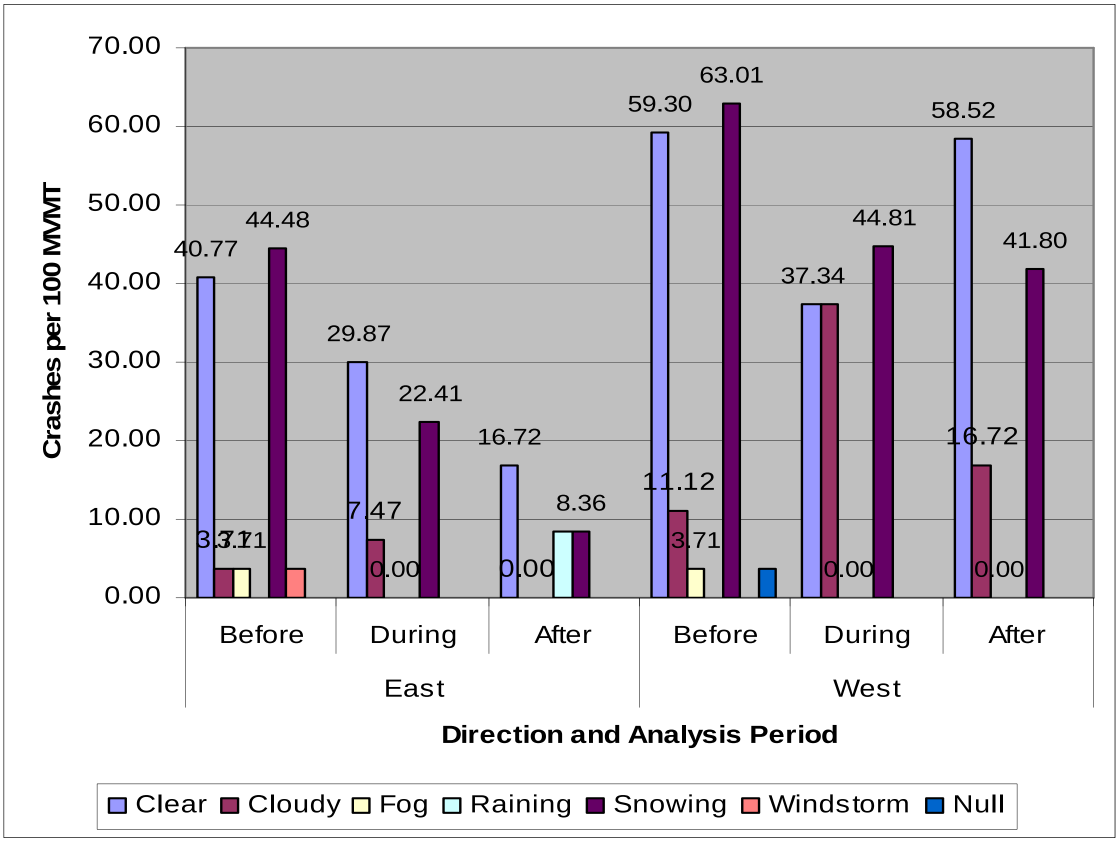

Figure C-14 Directional Distribution of Crash Rates by Weather Condition and Analysis Period (US-6 Study Site)

Road surface condition is closely related with the weather condition. Figure C-15 shows directional distribution crash rates by surface condition and analysis period. In general, crash rates were high for the 'dry' condition in both directions. Crash rates were much higher in the westbound direction than in the eastbound direction.

Crash rates by surface condition decreased as analysis period progressed from before to after construction. This was not the case for the westbound direction except for the crash rates for the 'icy' surface condition. It seemed that the westbound continued to exhibit some problems related to alignment and road surface condition.

In general, crash rates are high in the 'dry' condition in both directions. As time passed, crash rates in all surface condition decreased except those for the 'dry' condition in the westbound direction. Crash trends in relation to surface condition in the eastbound direction were similar to those in the westbound direction except that some crashes in the eastbound direction were related to the 'wet' surface condition.

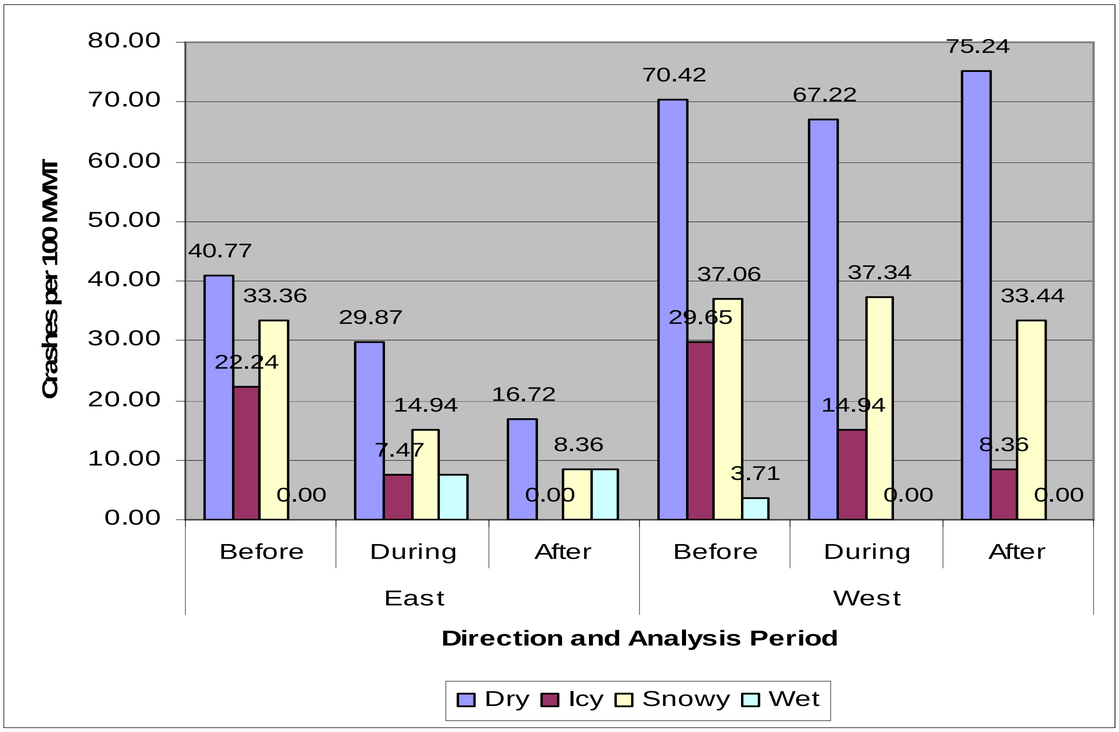

Figure C-15 Directional Distribution of Crash Rates by Surface Condition and Analysis Period (US-6 Study Site)

Table C-7 shows crash rates by involvement type for the three time period for both directions. Crashes involving a 'single vehicle' were more frequent than those involving 'multi-vehicle'. More than two-thirds of crashes were 'single vehicle' crashes in all time periods and directional contributions except the before construction period of the eastbound direction. Higher crash rates of the multi-vehicle collision type were found in the westbound direction during construction than before and after construction.

Table C-7 Crash Rates by Involvement Type (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	Eastbound			Westbound		
	Before	During	After	Before	During	After
MV-MV*	33.36	14.94	0.00	18.53	29.87	25.08
Single vehicle	63.01	44.81	33.44	122.31	89.62	91.96
Total	96.36	59.75	33.44	140.84	119.50	117.04

*: MV - MV: Motor Vehicle – Motor Vehicle

Table C-8 shows crash type breakdown by direction during construction. In all directions, the crash type of the highest frequency was the 'MV-animal (wild)'. In the eastbound direction, only three crash types were recorded, which were 'MV-wild animal', 'ran off roadway-left', and 'MV-MV'. On the other hand, more crash types were recorded in the westbound direction. The number of crashes related to multi-vehicle crashes ('MV-MV') in the westbound direction was twice as large as those in the eastbound direction.

Table C-8 Crash Type Breakdown by Direction during Construction (US-6 Study Site)

(Unit: Number of crashes)

Number of Vehicle	Accident Type	East	West	Total
Single Vehicle	MV-Animal(Wild)	4	5	9
	MV-Fixed Object	0	2	2
	MV-Other Object	0	0	1
	Ran Off Roadway-Left	0	2	2
	Ran Off Roadway-Right	2	3	5
MV-MV	MV-MV	2	4	6
	MV-MV(Ran Off Roadway-Right)	0	0	0
Total		8	16	25

C.1.3 Analysis by Construction Phase

C.1.3.1 Outline

The construction work at this study site was divided into three phases. The duration of Phase I was 13 months from April of 2002 to May of 2003, that of Phase II was one month from May of 2003 to June of 2003, and that of Phase III was one month from June of 2003 to July of 2003. Widening was the main work for Phase I, rehabilitation for Phase II, and chip seal for Phase III.

Crash rates in each phase were 211.13 crashes per 100 MVMT for Phase I, 392.10 crashes per 100 MVMT for Phase II, and 130.70 crashes per 100 MVMT for Phase III, respectively. Phase II had the highest crash rate among the three phases. Table C-9 provides basic information for each construction phase of this study site. Note that the reader must keep in mind that Phase I covered one year, four seasons, while Phase II and Phase III covered only the month of May and June, respectively.

Table C-9 Phase Information (US-6 Study Site)

Phase	Phase I	Phase II	Phase III
Time	4/02 - 05/03	5/03 - 6/03	6/03 - 7/03
During	13 months	1 month	1 month
Main Construction Type	Widening	Rehab. Removing Existing	Chip Seal
# of Crashes	21	3	1
Annual Average Crashes	19.38	36	12
Crashes per 100 MVMT	211.13	392.10	130.70

C.1.3.2 Spatial and Temporal Crash analysis

Figure C-16 shows spatial distribution of crashes in the work zone by phase. Crash occurrences in Phase I were distributed over the entire length of the work zone, but crash occurrences in Phase II and III were concentrated in one or more sections. It was difficult to pinpoint contributing causes from the engineers' notes and other design documents.

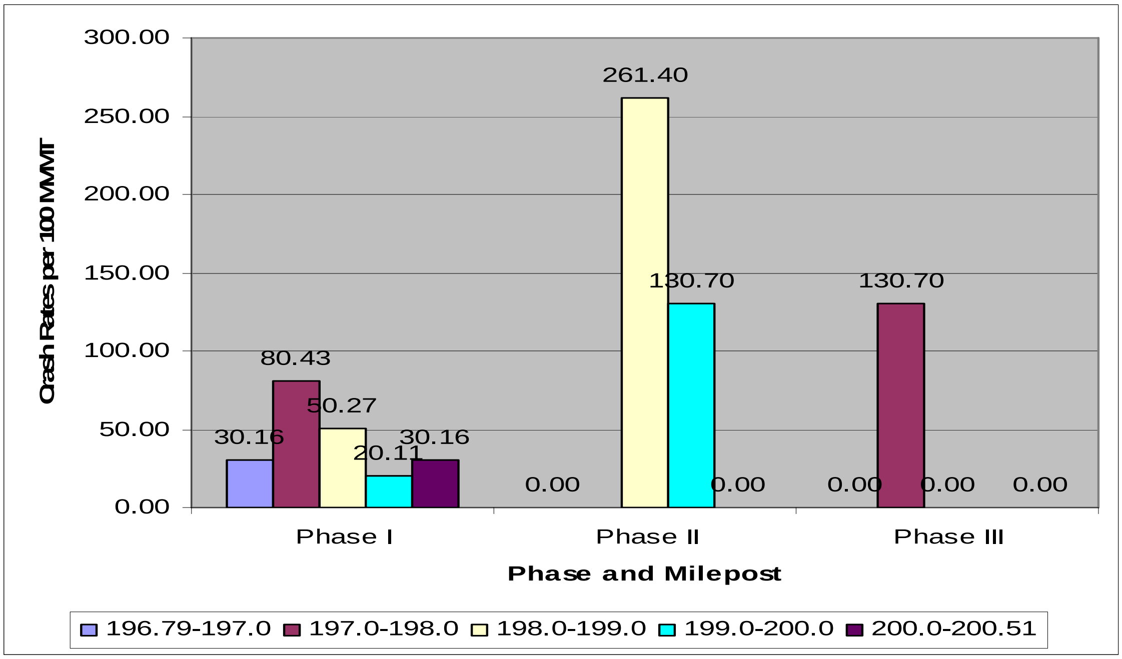

Figure C-16 Spatial Distribution of Crashes in the Work Zone by Phase (US-6 Study Site)

Table C-10 shows crash rates by severity and phase. Phase I experienced various types of crashes, Phase II and III experienced only the 'no injury' types. Phase I had severe crash types including fatal crashes.

Table C-10 Crash Rates by Severity and Phase (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	Phase I	Phase II	Phase III
No Injury	160.86	392.10	130.70
Possible Injury	20.11	0.00	0.00
Bruises and Abrasion	10.05	0.00	0.00
Broken Bones or Bleeding Blood	10.05	0.00	0.00
Fatal	10.05	0.00	0.00
Total	211.13	392.10	130.70

Figure C-17 shows the distribution of crashes by day of the week and phase. In Phase I, crash occurrences were spread out with Saturday's crash rate as the highest. On the other hand, crash occurrences in Phases II and III were more concentrated on a couple of days of the week and crash rates in Phases II and III were much higher than in Phase I. However, it is difficult to pinpoint direct contributing causes from the available records.

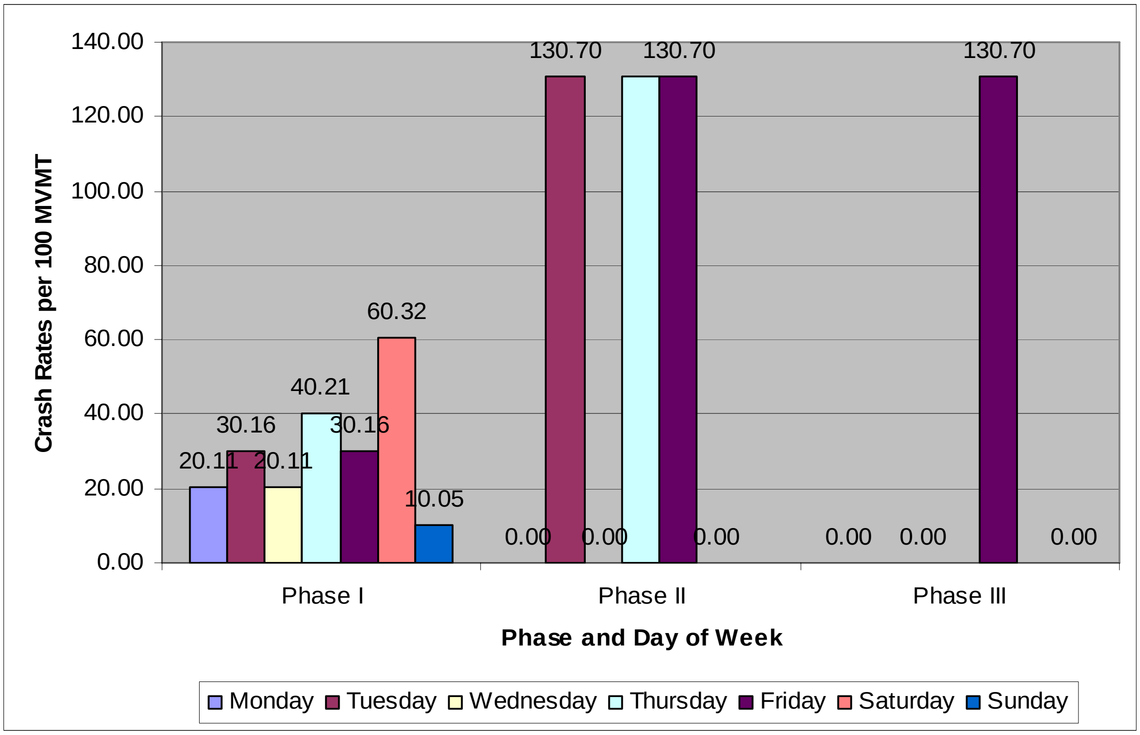

Figure C-17 Distribution of Crashes by Day of the Week and Phase (US-6 Study Site)

Figure C-18 shows the distribution of crash rates by light condition and phase. In all three phases, crashes took place in daylight condition. In Phase I and II, crashes also took place in the ‘dark street or highway not lighted’ condition. During Phase II, about two thirds of crashes took place in the ‘dark street or highway not lighted’ condition. In Phase I, a small number of crashes took places in the ‘dusk’ light condition.

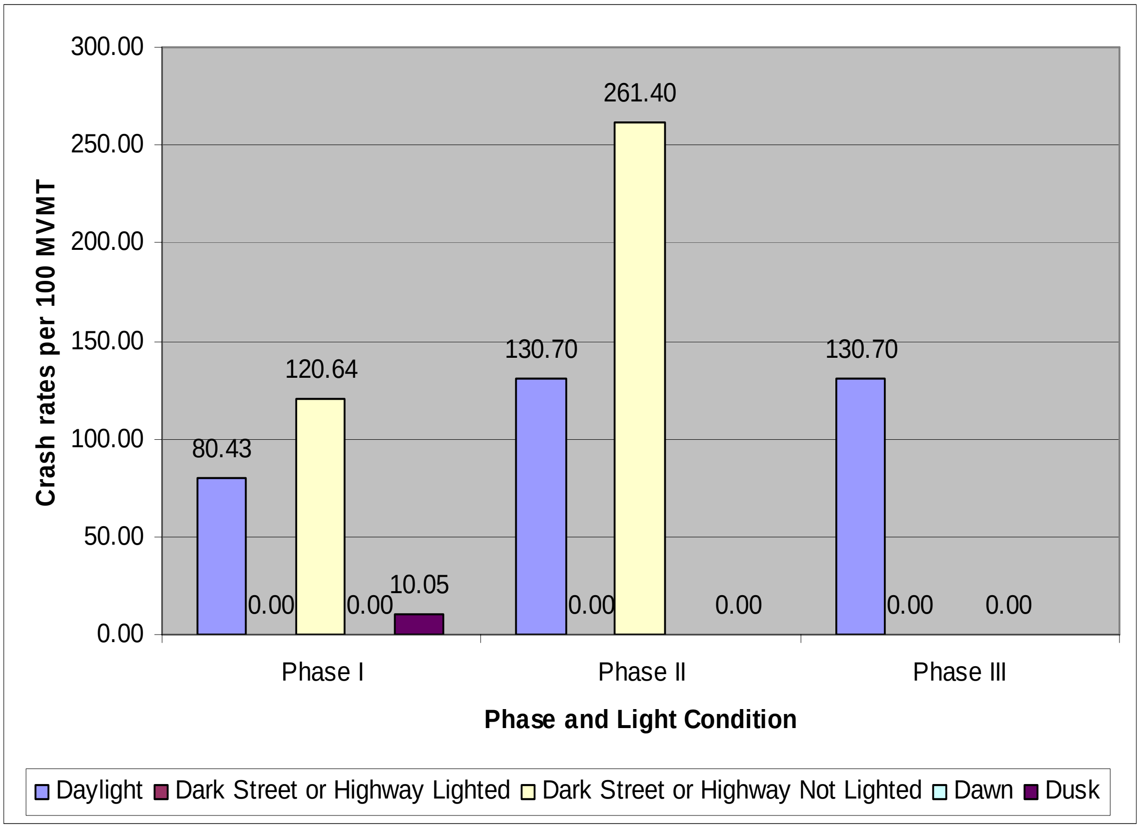

Figure C-18 Distribution of Crash Rates by Light Condition and Phase (US-6 Study Site)

Figure C-19 shows the distribution of crash rates by traffic control method and phase. In all phases, crashes took place where the 'traffic lanes were marked' traffic control was, which means that they took place in the travel lanes. The second highest crash rate resulted in the no-passing lanes (zones) in Phase II.

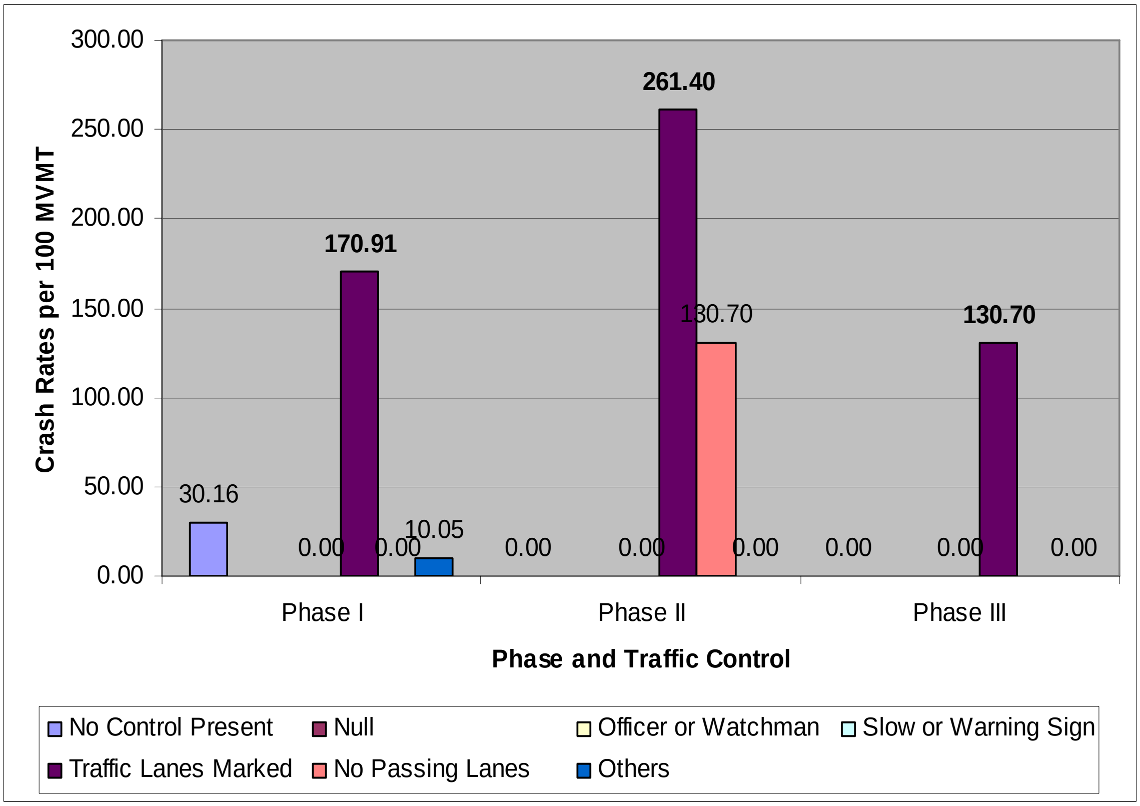

Figure C-19 Distribution of Crash Rates by Traffic Control Method and Phase (US-6 Study Site)

Figure C-20 shows the distribution of crash rates by alignment and phase. The trend of Phase I was different from Phase II and III. While crashes in Phase I took place at various alignment types, those of Phase II and III were more concentrated in one alignment type. Crashes in Phase II took place in the 'straight level' alignment section, while crashes in Phase III took place in the 'hillcrest straight' alignment.

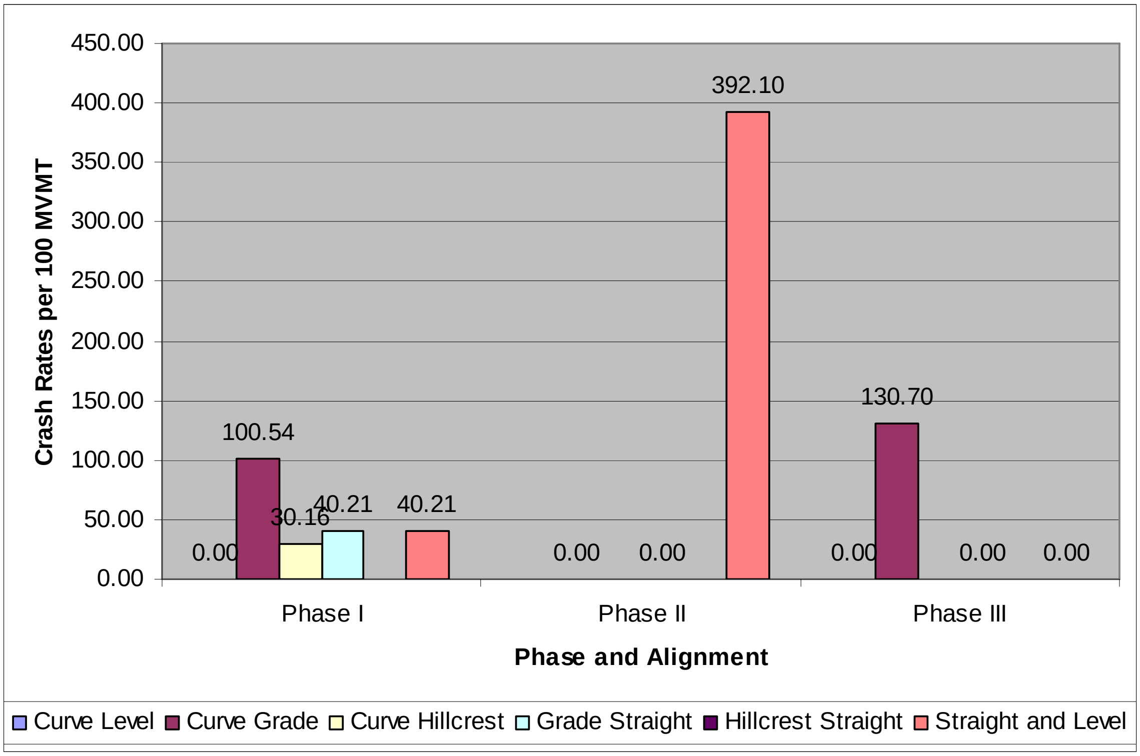

Figure C-20 Crash Rates by Alignment and Phase (US-6 Study Site)

Figure C-21 shows the distribution of crash rates by weather condition and phase. Most crashes took place in the 'clear' and 'cloudy' weather conditions. As for Phase I, the crash rate for the 'snowing' condition was the highest. This is understandable because Phase I had a winter season, but Phases II and III had only the months of May and June.

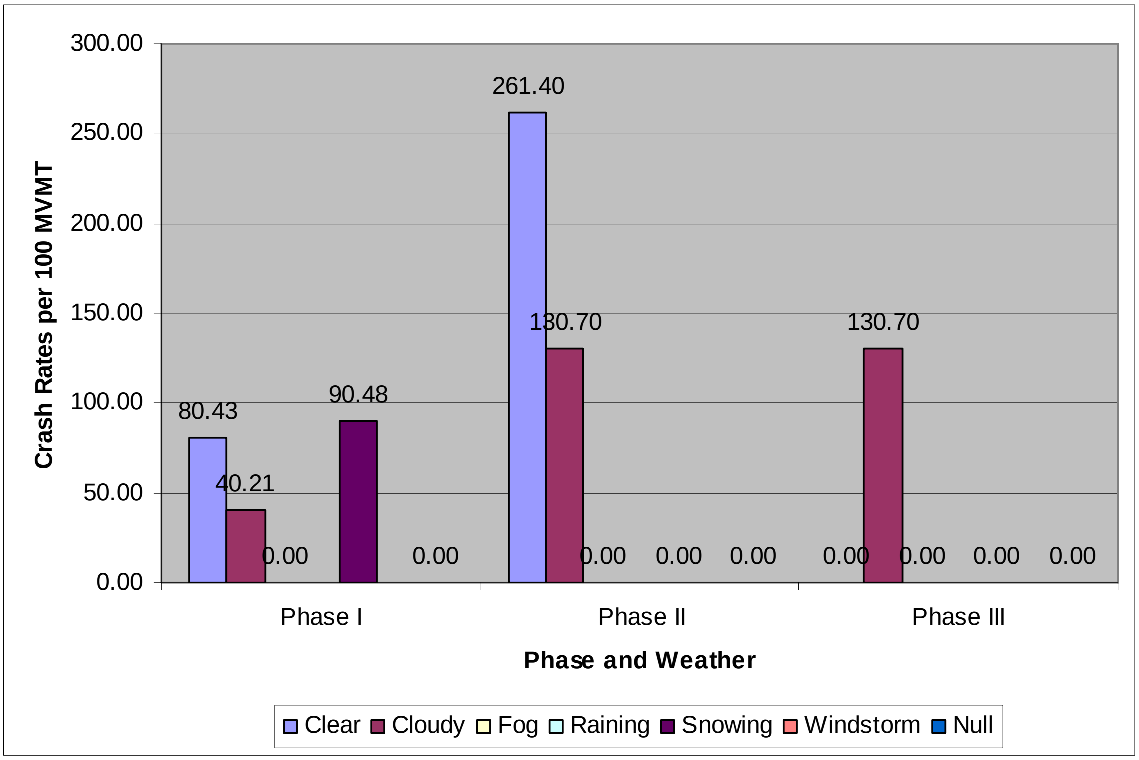

Figure C-21 Distribution of Crash Rates by Weather Condition and Phase (US-6 Study Site)

Surface condition is closely related to weather condition. Figure C-22 shows the distribution of crash rates by surface condition and phase. During Phase I, crash rates were relatively low compared to those in Phase II and III and spread over the four surface conditions shown. Crashes in Phase II and III took place in the month of May and June; hence, their crashes basically took place when the pavement in 'dry' surface condition. Nevertheless, crash rate for dry condition in Phase II was exceptionally high. It might be related to how the traffic control for the rehabilitation was done. However, data were not available to help to identify contributing causes.

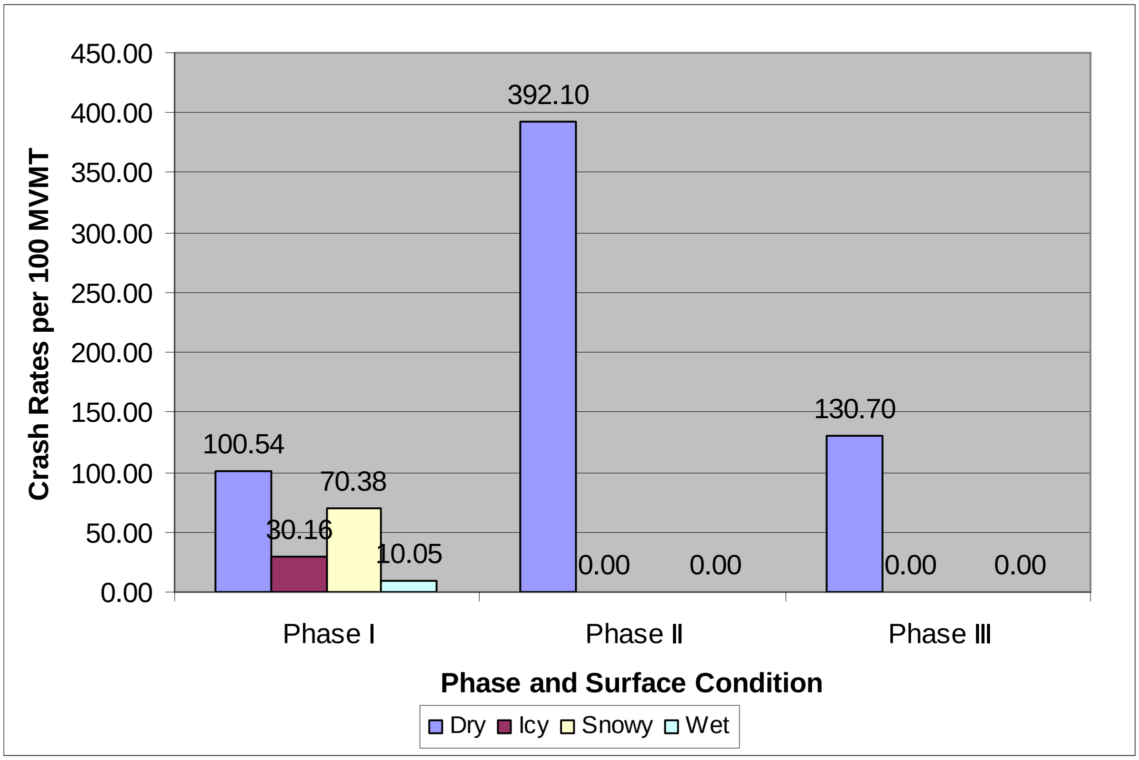

Figure C-22 Distribution of Crash Rates by Surface Condition and Phase (US-6 Study Site)

Table C-11 shows crash rates by involvement and phase. The majority of crashes involved 'single vehicle'. Multi-vehicle crashes ('MV-MV') took place only in Phase I.

Table C-11 Crash Rates by Involvement and Phase (US-6 Study Site)

(Unit: Crashes per 100MVMT)

	Phase I	Phase II	Phase III
MV-MV	60.32	0.00	0.00
Single vehicle	150.81	392.10	130.70
Total	211.13	392.10	130.70

Table C-12 shows crash breakdown type by phase. Phase I lasted one year; hence, it was natural that various types of crashes took place in Phase I. There were no crashes related to 'multi-vehicles' in Phase II and III. Note that these phases lasted only one month each. In Phase I, 80 percents of 'single vehicle' related crashes were related to three crash types including 'MV-wild animal', 'ran-off roadway-right', and 'MV-MV'. There were a few crashes of the other crash types related to 'single vehicle'. In Phase II, crashes involved the 'vehicle-wild animal' and 'ran-off roadway-right' types. One crash that took place in Phase III was of the 'MV-fixed object' type. Note that Phase I lasted for one year; hence, it is natural to see crash types taking place in the work zone.

Table C-12 Crash Breakdown Type by Phase (US-6 Study Site)

(Unit: Number of crashes)

Number of Vehicle	Breakdown Type	Phase I	Phase II	Phase III
Single Vehicle	MV-Animal(Wild)	7	2	0
	MV-Fixed Object	1	0	1
	MV-Other Object	1	0	0
	Ran Off Roadway-Left	2	0	0
	Ran Off Roadway-Right	4	1	0
	Subtotal	15	3	1
MV-MV	MV-MV	6	0	0
	MV-MV(Ran Off Roadway-Right)	0	0	0
	Subtotal	6	0	0
Total		21	3	1

C.1.4 Seasonal Analysis

C.1.4.1 General Outline

To analyze the crash distribution in summer, crashes which happened in June, July, August 2002 and 2003 during construction were considered. Table C-13 shows the crash rates in summer together with the total crashes during construction. Even though the number of crashes was below 30 percent of all crashes that happened during the entire construction period, the annual average number of crashes for the three summer months was larger than that for the entire construction period. Compared with Table 4-1, the seasonal crash rates per 100 MVMT for the summer season before construction (355.80) and after construction (384.09) except for the during construction (199.96) were much larger than the total crash rates per

100 MVMT for the total construction time for before construction (244.61) and after construction (66.88), respectively.

Table C-13 Comparison of Crash Frequency and Rate of the Summer Season (US-6 Study Site)

Construction Time	Total Crashes (Number of Crashes)			Annual Average Number of Crashes (Crashes/Year)		
	Before	During	After	Before	During	After
04/00/2002 – 08/15/2003	65	25	18	21.67	17	15
Summer Season (June, July, August)	**8**	**7**	**6**	**32.0**	**18.1**	**31.0**

Figure C-23 shows crash rates for the three summer months by severity level. Like Table 4-1, the crash severity type for three summer months had a similar trend to that of the entire construction time for example 'no injury' had the highest crash rate. Note that there was no fatal crash recorded for the three summer months before, during, and after construction. Major crash types were 'no injury' and 'broken bones or bleeding blood'. After construction, crash severity of the studied section increased as indicated by an increase in the crash rates of 'broken bones or bleeding blood' from 44.48 crashes per 100 MVMT to 115.19 crashes per 100 MVMT.

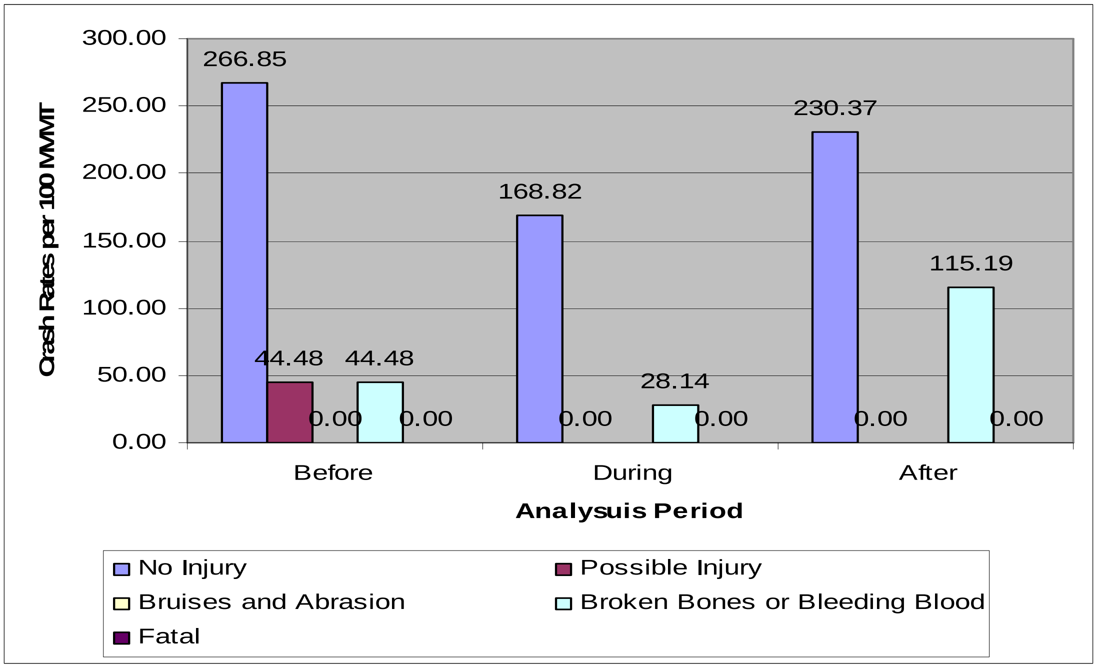

Figure C-23 Crash Rates for the Three Summer months by Analysis Period and Severity (US- 6 Study Site)

C.1.4.2 Spatial and Temporal Crash Analysis

Figure C-24 compares the seasonal spatial and temporal crash rate by milepost in the work zone. Compared with Figure C-2, crash occurrences were concentrated on some sections and no patterns were identified. Except for 'during' construction period, the highest crash rate occurred in one mile section between MP 197.0 and MP 198.0. The highest crash rate during construction occurred in the section between MP 198.0 and MP 199.0. It was interesting that the crash rate for the section between MP 197.0 and MP 198.0 after construction sharply increased. Unlike the general trend, no crashes in the edge sections between MP 196.79 and MP 197.0 happened.

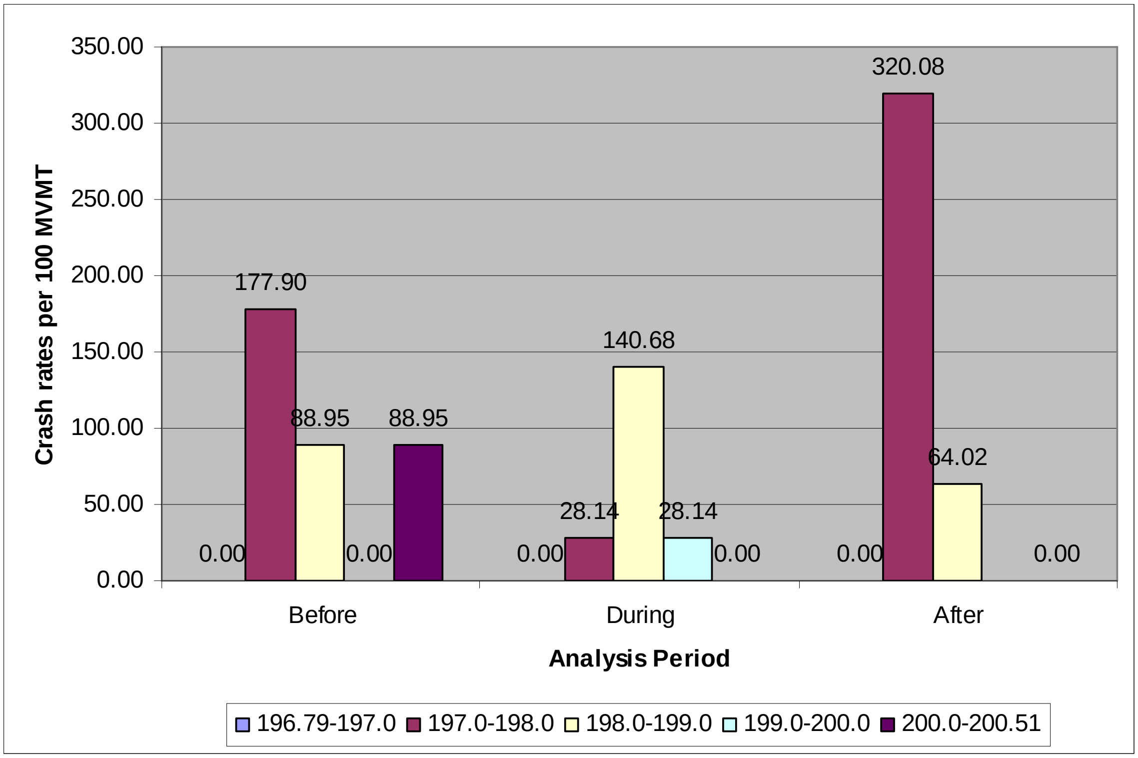

Figure C-24 Spatial and Temporal Crash Rate Distribution for the Three Summer Months by Analysis Period and Milepost in Work Zone (US-6 Study Site)

Figure C-25 shows hourly crash rate distribution during construction. Total number of crashes was seven. Three crashes took place peak time (7:00AM-9:00AM, 5:00PM-7:00PM). At night, two crashes happened, and two crashes occurred at day time. 71.4 percent of the total crashes took place during the day.

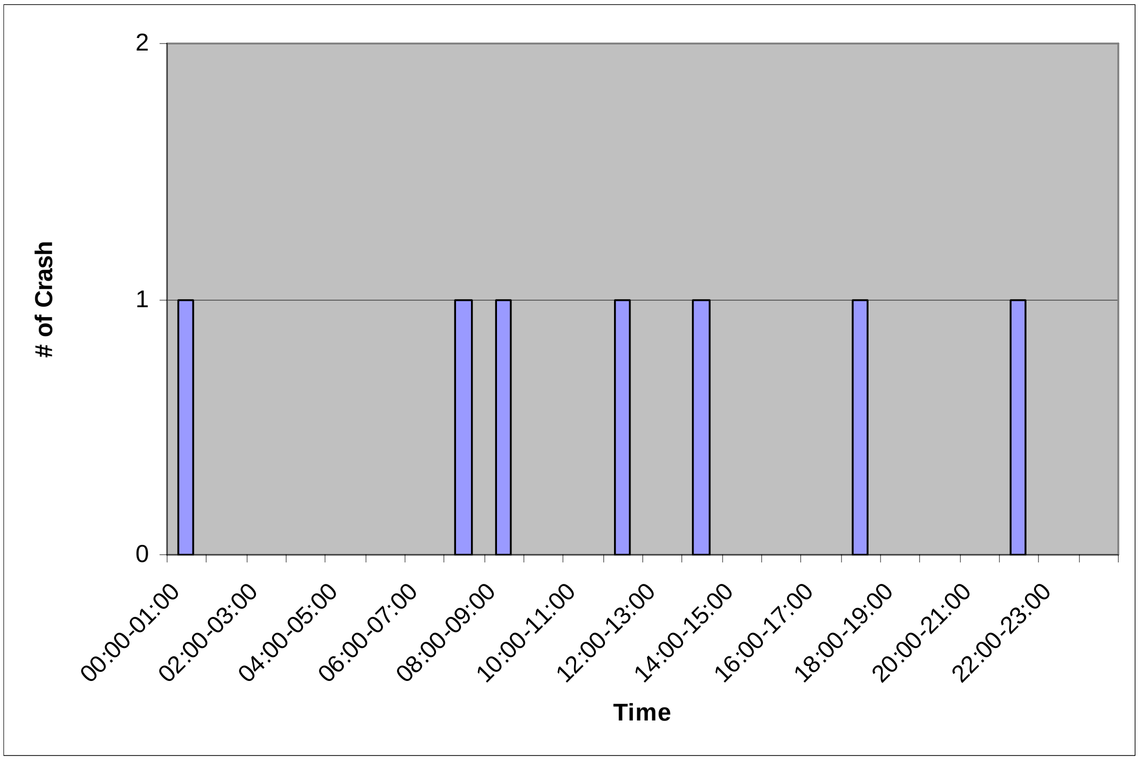

Figure C-25 Hourly Crashes Occurrence during Construction (US-6 Study Site)

Figure C-26 shows seasonal crash distribution in percentages by day of the week. Among the before, during, and after construction periods, different characteristics emerged in the seasonal crash distributions by day of the week. Crashes before and after construction took place throughout the week, except on Tuesday before construction and on Monday after construction. On the other hand, crashes during construction took place on three days of the week, Tuesday, Thursday, and Friday. Monday had the highest crash occurrence before construction, Thursday and Friday during construction. Crashes after construction occurred from Tuesday to Sunday. The available crash data and project records do not provide definitive reasons to determine causes of three different weekly crash distribution patterns.

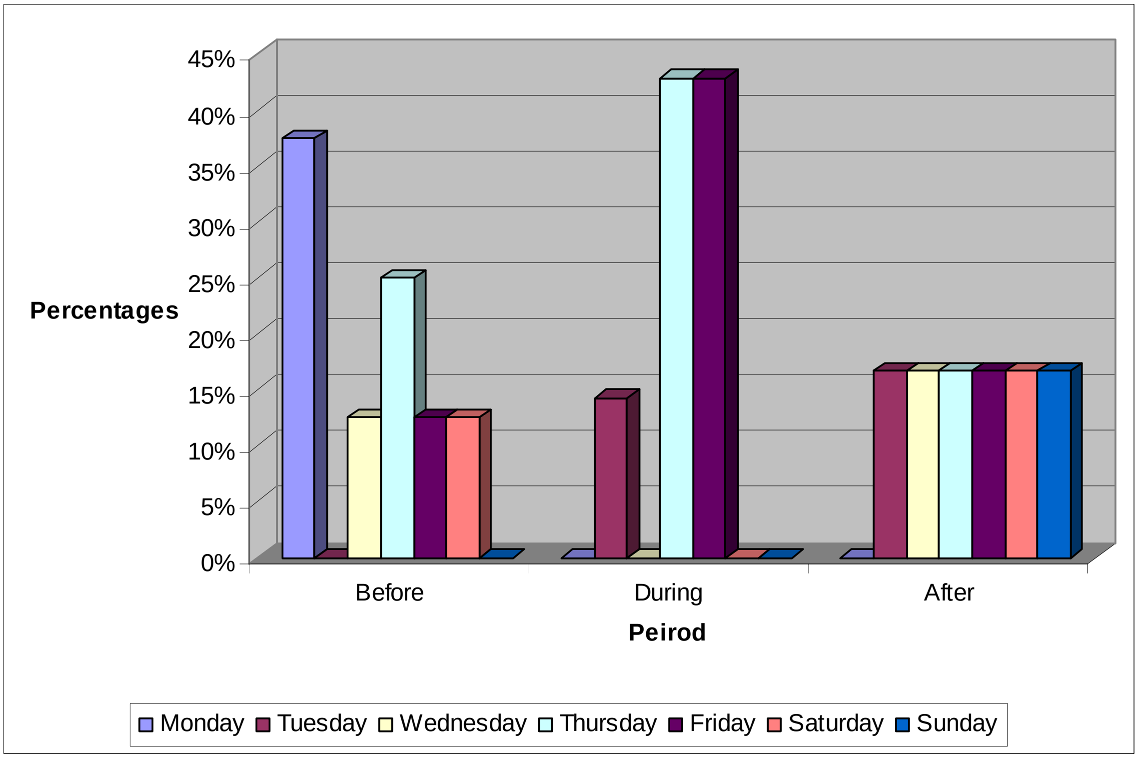

Figure C-26 Weekly Crash Occurrences by Analysis Period (US- 6 Study Site)

C.1.4.3 Other Analyses

Figure C-27 shows a crash rate distribution by light condition and analysis period. Most crashes except during the before period took place in the 'daylight' and 'dark street or highway not lighted' light conditions. Some crashes happened in the 'dawn' and 'dusk' light conditions before construction, but no crashes were found in the during and after construction periods. These trends found in the three summer months are similar to the trends found in the entire construction period as seen in Table C-2.

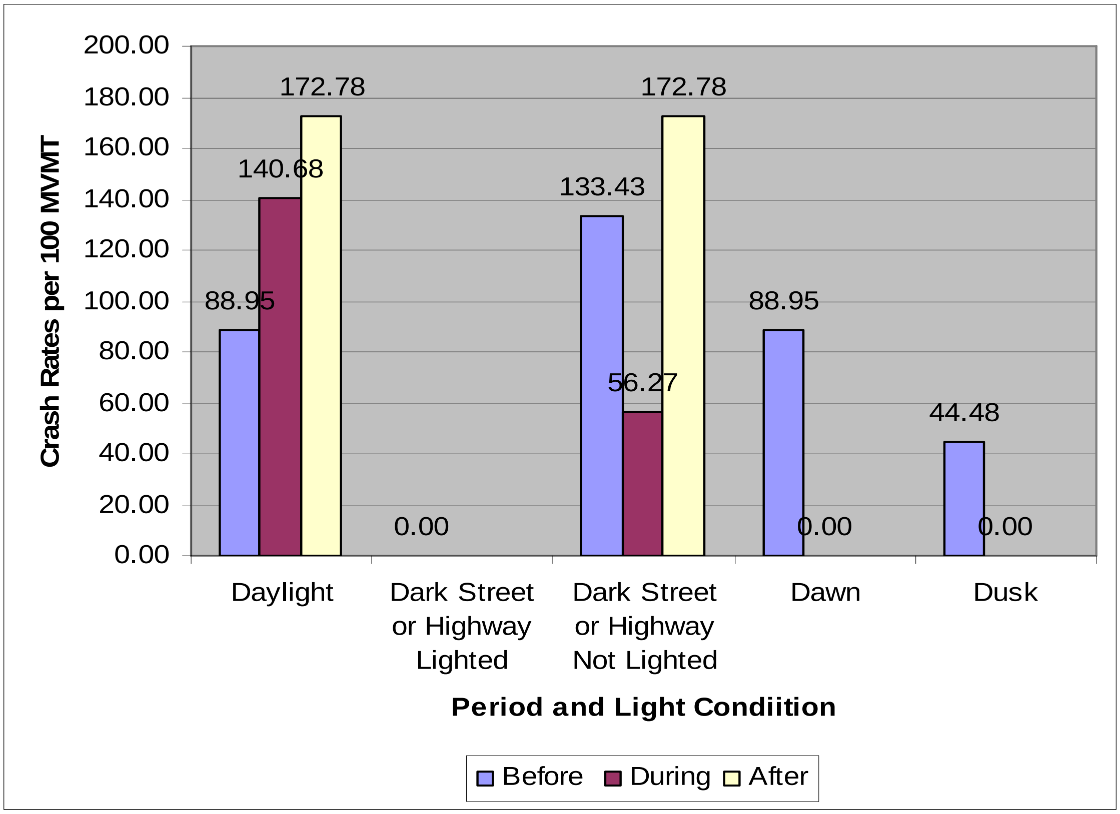

Figure C-27 Crash Rates Distribution by Light Condition and Analysis Period (US-6 Study Site)

Figure C-28 shows crash rate distribution by analysis period and traffic control of the location where crashes took place. In the three analysis periods, crash rates were the highest in the 'traffic lane marked' traffic control. The highest crash rate after construction is seen in the 'traffic lanes marked' traffic control. Some crashes were focused on the 'no control present' and 'slow or warning sign' traffic controls before construction, and other crashes recorded were found in the 'no passing lanes' condition during and after construction periods. These trends found in the summer month data are similar to the trends found for the entire construction period.

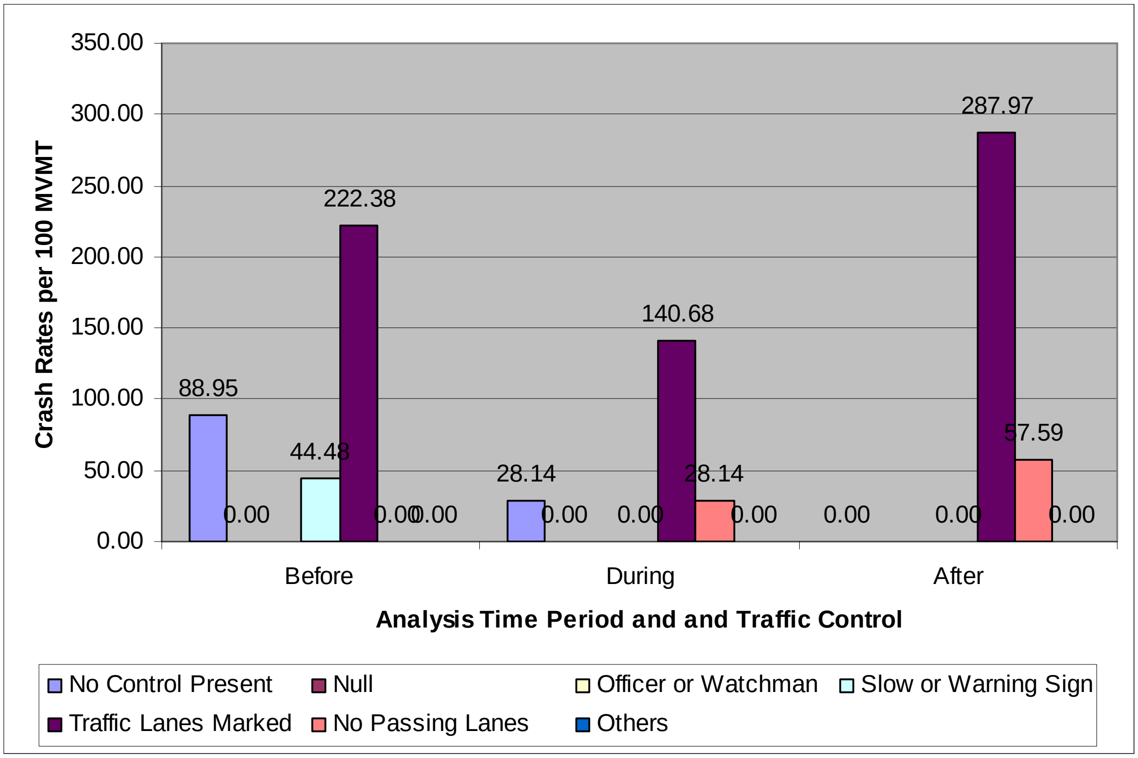

Figure C-28 Crash Rate Distribution by Analysis Period and Traffic Control (US-6 Study Site)

Figure C-29 shows crash rate distribution by analysis period and alignment type. The highest crash rates by alignment were different in each analysis period; the ‘curve grade’ section before construction, the ‘straight and level’ section during period, and the ‘grade straight’ section after construction. Crashes happened in the ‘curve grade’ section for all the three analysis periods. After construction, crashes newly appeared in the ‘curve level’, and ‘hillcrest straight’ sections, while crashes disappeared in the ‘curve hillcrest’ sections. These trends found in the summer month data are different from those of the trends observed in crash rates by analysis period and traffic control type for the entire construction period, as seen in Figure 4-5.

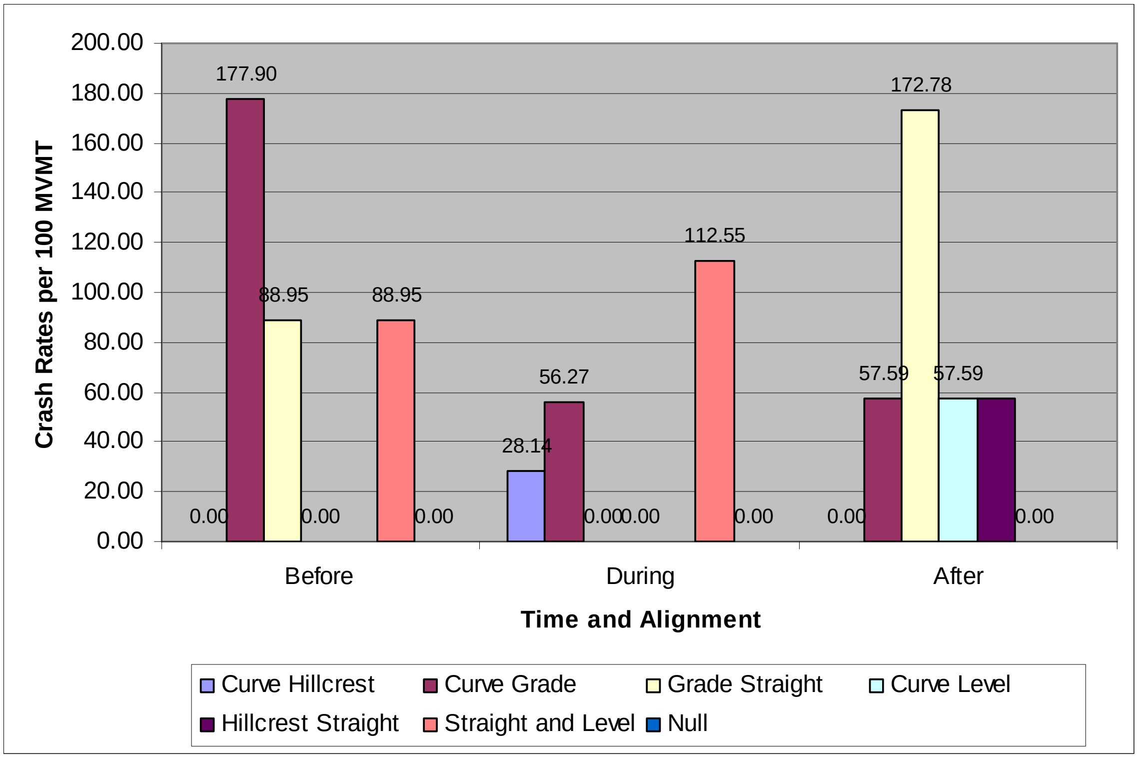

Figure C-29 Crash Rate Distribution by Analysis Period and Alignment Type (US-6 Study Site)

Table C-14 presents crash rate distribution by weather condition. Most crashes happened in the 'clear' weather condition, while some happened in the 'cloudy' condition. These trends are different from those found for the entire construction period, as seen Table C-2. Obviously much less 'fog', 'raining', and 'windstorm' conditions is experienced in summer months. All crashes took place on the 'dry' surface condition for each period.

Table C-14 Crash Rate Distribution by Analysis Period and Weather Condition (US-6 Study Site)

	Before	During	After
Clear	355.80	140.68	345.56
Cloudy	0.00	56.27	0.00
Fog	0.00	0.00	0.00
Raining	0.00	0.00	0.00
Windstorm	0.00	0.00	0.00
Total	355.80	196.96	345.56

Table C-15 shows crash rate distribution by vehicle involvement. Except in the after period, all crashes were involved in a 'single vehicle' crash. This trend for the summer months is different from the trend seen in the crashes for the entire construction, as seen Table C-3.

Table C-15 Crash Rate Distribution by Analysis Period and Vehicle Involvement (US-6 Study) Site)

	Before	During	After
MV-MV	0.00	0.00	57.59
Single vehicle	355.80	196.96	287.97
Total	355.80	196.96	345.56

Table C-16 shows the number of crashes that took place in the three summer months during construction by crash type. The 'MV-Wild Animal' crash type was the major crash type involving 'single vehicle'. There were no 'multi-vehicles' crash types ('MV-MV') in the three summer months. These trends are different from those for the entire construction period, as seen in Table C-4.

Table C-16 Number of Crashes by Crash Type During Construction (US-6 Study Site)

Number of Vehicle	Crash Type	#of Crashes
Single Vehicle	MV-Animal(Wild)	3
	MV-Fixed Object (MV-Other Object)	1
	MV-Fixed Object (Overturned)	0
	MV-Other Object	1
	Ran Off Roadway-Left	1
	Ran Off Roadway-Left (MV-Fixed Object)	0
	Ran Off Roadway-Right (MV-Fixed Object)	1
	Ran Off Roadway-Right (Overturned)	0
MV-MV	MV-MV	0
	MV-MV(Ran Off Roadway-Right)	0
Total		7

C.1.5 Summary and Conclusion

C.1.5.1 General Outline

Table C-17 summarizes the results of spatial and temporal analyses of the work zone on US-6. This was a rehabilitation and reconstruction project. The span of the work zone was 3.72 miles and the construction duration was 16.5 months. Traffic control cost occupied 1.4 percents of total construction costs.

The crash analysis by severity showed that while the 'broken bones or bleeding blood' crash rate during the construction period was the lowest among three analysis periods, the fatal crash rate during construction was the highest.

The spatial and temporal crash analysis revealed that at this site, upstream and downstream sections of the work zone were more dangerous than the work zone. Sections with the highest number of 'broken bones and bleeding blood' and 'fatal' crashes were 'four- or five-mile' east or west sections of the work zone for the three construction periods, except for the number of fatal crashes after construction. The section with the highest change in the 'broken bones or bleeding blood' crash rate was located in the 'four-mile' east section of the work zone, i.e., from MP 203.52 to MP 204.51, and the section with the highest change in the 'fatal' crash changes was located in the 'one-mile' west section of the work zone, from MP 195.79 to MP 196.78.

The spatial and temporal crash rate comparison by milepost in the work zone showed that the section with the highest change in crash rates was the same as time progressed from before construction to after construction. It was from MP 197.00 to MP 198.00 for the all three construction periods. Within the work zone (from MP 196.79 to MP 200.51), and the end section of the work zone (from MP 197.00 to MP 198.00) were the most dangerous. The one mile section with the highest increase in crash rates was found to be in the end section from MP 197.0 to MP 198.0.

The monthly crash rate distribution analysis showed that April of 2002 and of 2003 and May of 2003 were the months with the highest crash rate with 25.30 crashes per 100 MVMT. The months with the lowest crash rates were July of 2002, and January, June, and July of 2003, with 0.00 crashes per 100 MVMT all summer months.

Table C-17 Summary of Spatial and Temporal Analysis Results (US-6 Study Site)

Main Factor		Contents	
General Outline			
	Construction Duration	April 2002 - August 2003	16.5 months
	Span of Work Zone	MP 196.79 - 200.51	3.72 miles
	Main Works	Rehabilitation & Reconstruction	Widening, Hot-mix Asphalt Paving, Chip Seal
	Traffic Control Cost	$150,000	1.4 % of Total Construction Cost ($10.8 million)
Crash Rate Analysis by Severity (Crashes per 100 MVMT)			
	Before (Apr. 1999 - Apr. 2002)	Broken Bones or Bleeding Blood (BBBB)	29.67
		Fatal	3.71
	During (Apr. 2002 – Aug. 2003)	Broken Bones or Bleeding Blood	8.43
		Fatal	8.43
	After (Aug. 2003 - Dec. 2004)	Broken Bones or Bleeding Blood	16.72
		Fatal	8.36
Spatial and Temporal Crash Analysis (Crashes per 100 MVMT)			
	Before	Section with the Highest BBBB Crash Rates	West 5 mile (MP 191.79-192.78, 68.54)
		Section with the Highest Fatal Crash Rates	West 4 mile (MP 192.79-193.78, 13.79)
	During	Section with the Highest BBBB Crash Rates	East 4 mile (MP 203.52 - 204.51, 62.74)
		Section with the Highest Fatal Crash Rates	West 1 mile (MP 195.79 - 196.78, 62.74)
	After	Section with the Highest BBBB Crash Rates	West 5 mile (MP 191.79-192.78, 93.30)
			East 1 mile (MP 200.52 - 201.51, 93.30)
		Section with the Highest Fatal Crash Rates	Construction Zone (MP 196.79-200.51, 8.36)
	Section with the Highest Increasing BBBB Crash Rates From Before to After		East 1 mile (MP 200.52 - 201.51, 0.00 → 93.30)
	Section with the Highest Decreasing BBBB Crash Rates From Before to After		West 1 mile (MP 195.79 - 196.78, 41.36 → 0.00)
	Section with the Highest Increasing Fatal Crash Rates From Before to After		Construction Zone (MP 196.79-200.51, 3.79 → 8.36)
	Section with the Highest Decreasing Fatal Crash Rates From Before to After		West 4 mile (MP 192.79-193.78, 13.79 → 0.00)
	Section with the Highest BBBB Crash Rate Changes From Before To During Construction		East 4 mile (MP 203.52 - 204.51, 13.79 → 62.74)
	Section with the Highest Fatal Crash Rate Changes From Before To During Construction		West 1 mile (MP 195.79 - 196.78, 0.00 → 62.74)
Spatial and Temporal Crash Rate Comparison by Milepost in Work Zone (Crashes per 100 MVMT)			
	Before	Section with the Highest Crash Rates	MP 197.0-198.0 (77.83)
		Section with the Lowest Crash Rates	MP 200.01-200.51 (22.24)
	During	Section with the Highest Crash Rates	MP 197.0-198.0 (67.22)
		Section with the Lowest Crash Rates	MP 196.79 - 197.00, MP 199.01-200.51 (22.41)
	After	Section with the Highest Crash Rates	MP 197.0-198.0 (111.51)
		Section with the Lowest Crash Rates	MP 196.79 - 197.00, MP 200.01-200.51 (0.00)
	Section with the Largest Increase in Crash Rates From Before To After		MP 197.0-198.0 (77.83 → 111.51)
	Section with the Largest Decrease in Crash Rates From Before To After		MP 196.79 -197.0 (40.77 → 0.00)
Monthly Crash Rate Distribution Analysis During Construction (Crashes per 100 MVMT)			
	Month with the Highest Crash Rates		Apr 2002, Apr 2003, and May 2003 (25.30)
	Month with the Lowest Crash Rates		Jul 2002, Jan 2003, Jun 2003, and Jul 2003 (0.00)

Table C-18 summarizes the analysis results between crash rates and other factors such as light condition, traffic control method, alignment, weather condition, and surface condition.

The crash rate analysis by severity and light condition during construction showed that all ‘broken bones or bleeding’ crashes happened in the ‘daylight’ condition and all ‘fatal’ crashes happened in the ‘dark street or highway not lighted’ condition. The majority of crashes (56.0 percent) took place in the ‘dark street or highway not lighted’ condition, followed by the ‘daylight’ condition (40.0 percent).

The crash rate analysis by analysis period and traffic control showed that most of the crashes took place in the ‘traffic lanes marked’ sections during the three periods. The highest increase in crash rates from before to after construction happened in the section with ‘no passing lanes’ traffic control, while the largest decrease in crash rates from before to after construction happened in the section with the ‘no control present’ traffic control.

The crash rate analysis by analysis period and alignment showed that ‘curve grade’ sections had the largest increase in crash rates, while ‘curve level’ and other sections had the smallest increase in crash rates. After construction, the alignment type that has the lowest increase in crash rates was the ‘curve grade’ alignment type.

The crash rate analysis by analysis period and weather condition showed that the highest increase in crash rates happened in the ‘snowing’ weather condition for before construction and in the ‘clear’ condition for during and after construction. The weather condition with the lowest increase in crash rate was the ‘snowing’ condition after construction.

The crash rate analysis by analysis period and surface condition showed that the highest increase in crash rate change took place in the ‘dry’ surface condition, while the lowest increase in crash rate change took place in the ‘wet’ or ‘icy’ condition. After construction, the surface condition with the lowest increase in crash rate was the ‘icy’ condition.

The analysis of the number of crashes by crash type during construction showed that the crash type with the highest number of crashes was the 'MV-wild animal' crash types, with 9 crashes out of the total 25 total crashes.

Table C-18 Summary of Other Analysis Results (US-6 Study Site)

Main Factor			Contents
Crash Rate Analysis by Severity and Light Condition during Construction (Crashes per 100 MVMT)			
	Broken Bones or Bleeding Blood		Daylight (10.89)
	Fatal		Dark Street or Highway Not Lighted (10.89)
	Percentage Share of Light Condition for Crashes		Dark Street or Highway Not Lighted (56.0%)
			Daylight (40.0%)
			Dusk (4.0%)
Crash Rate Analysis by Analysis Period and Traffic Control (Crashes per 100 MVMT)			
	Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (174.20)
		Traffic Control with the Lowest Crash Rates	No Passing Lanes (0.00)
	During	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (168.64)
		Traffic Control with the Lowest Crash Rates	Office or Watchman, Slow or Warning Sign (0.00)
	After	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (120.82)
		Traffic Control with the Lowest Crash Rates	Office or Watchman (0.00)
	Traffic Control with the Largest Increase in Crash Rates From Before To After		No Passing Lanes (0.00 → 8.63)
	Traffic Control with the Largest Decrease in Crash Rates From Before To After		No Control Present (498.18 → 0.00)
Crash Rate Analysis by Analysis Period and Alignment (Crashes per 100 MVMT)			
	Before	Alignment with the Highest Crash Rates	Curve Grade (122.31)
		Alignment with the Lowest Crash Rates	Curve Level (0.00)
	During	Alignment with the Highest Crash Rates	Curve Grade (92.75)
		Alignment with the Lowest Crash Rates	Curve Level (0.00)
	After	Alignment with the Highest Crash Rates	Curve Grade (74.34)
		Alignment with the Lowest Crash Rates	Curve Hillcrest, Curve Level, Hillcrest Straight (9.29)
	Alignment with the Largest Increase in Crash Rates From Before To After		Curve Level (0.00 → 9.29)
	Alignment with the Largest Decrease in Crash Rates From Before To After		Curve Grade (122.31 → 74.34)
Crashes Rate Analysis by Analysis Period and Weather Condition (Crashes per 100 MVMT)			
	Before	Weather Condition with the Highest Crash Rates	Snowing (107.48)
		Weather Condition with the Lowest Crash Rates	Raining (0.00)
	During	Weather Condition with the Highest Crash Rates	Clear (84.32)
		Weather Condition with the Lowest Crash Rates	Fog, Raining, Windstorm (0.00)
	After	Weather Condition with the Highest Crash Rates	Clear (83.63)
		Weather Condition with the Lowest Crash Rates	Fog, Windstorm (0.00)
	Weather Condition with the Largest Increase in Crash Rates From Before To After		Raining (0.00 → 9.29)
	Weather Condition with the Largest Decrease in Crash Rates From Before To After		Snowing (107.48 → 55.76)
Crashes Rates by Analysis Period and Surface Condition (Crashes per 100 MVMT)			
	Before	Surface Condition with the Highest Crash Rates	Dry (114.89)
		Surface Condition with the Lowest Crash Rates	Wet (3.71)
	During	Surface Condition with the Highest Crash Rates	Dry (118.05)
		Surface Condition with the Lowest Crash Rates	Wet (8.43)
	After	Surface Condition with the Highest Crash Rates	Dry (102.22)
		Surface Condition with the Lowest Crash Rates	Icy, Wet (9.29)
	Surface Condition with the Largest Increase in Crash Rates From Before To After		Wet (3.71 → 9.29)
	Surface Condition with the Largest Decrease in Crash Rates From Before To After		Icy (51.89 → 9.29)
Number of Crashes by Crash Types during Construction (Number of Crashes Involved Crash Type/ Total Number of Crashes)			
	The Highest Crash Type		MV-Animal (Wild) (9/25)

C.1.5.2 Directional Analysis

Table C-19 summarizes the results of spatial and temporal analyses by direction on US 6. According to crash rate analysis by direction, the westbound had more crashes and was more dangerous than the eastbound for the entire three analysis periods.

The spatial and temporal crash rate comparison by direction and milepost in the work zone revealed that one mile section with the highest crash rates were almost the same in eastbound and westbound direction as shown Table 4-20. The one-mile section with the largest increase in crash rate from before to after period was between MP 197.0 and MP 198.0 for eastbound and between MP 199.0and MP 200.0 for westbound, respectively.

The crash analysis by severity and direction showed that crashes which happened in the westbound direction were more severe than those in the eastbound direction for the three periods. In the eastbound direction, only 'broken bones or bleeding blood' crashes happened before construction, while they happened in the all three analysis periods in the westbound direction.

The monthly crash rate distribution by direction during construction showed that the months with the highest crash rates were April of 2002 for the eastbound direction and April, and May of 2002 and February, and May of 2003 for the westbound direction. The months with the lowest crash rates in the eastbound and westbound directions were different except toward the end periods of construction.

Table C-19 Summary of Spatial and Temporal Analysis Results by Direction (US-6 Study Site)

<table>
<tr><th colspan="2" rowspan="2">Main Factor</th><th colspan="2" rowspan="2">Contents</th><th colspan="2">Direction</th></tr>
<tr><th>Eastbound</th><th>Westbound</th></tr>
<tr><td colspan="6">Crash Rate Analysis (crashes per 100 MVMT)</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Before</td><td>96.36</td><td>140.84</td></tr>
<tr><td colspan="3">During</td><td>59.75</td><td>119.5</td></tr>
<tr><td colspan="3">After</td><td>33.44</td><td>122.3</td></tr>
<tr><td colspan="6">Spatial and Temporal Crash Rate Comparison by Direction Milepost in Work Zone (Crashes per 100 MVMT)</td></tr>
<tr><td rowspan="8"></td><td colspan="2" rowspan="2">Before (Apr. 1999 - Apr. 2002)</td><td>Section with the Highest Crash Rates</td><td>MP 198.0-199.0 (33.36)</td><td>MP 197.0-198.0 (44.18)</td></tr>
<tr><td>Section with the Lowest Crash Rates</td><td>MP 196.79-197.0, 200.01-200.51 (7.47)</td><td>MP 199.0-200.0 (7.47)</td></tr>
<tr><td colspan="2" rowspan="2">During (Apr. 2002 - Aug. 2003)</td><td>Section with the Highest Crash Rates</td><td>MP 197.0-199.0, 200.0-200.51 (14.94)</td><td>MP 197.0-198.0 (52.28)</td></tr>
<tr><td>Section with the Lowest Crash Rates</td><td>MP 196.79-197.0, 199.0-200.0 (7.47)</td><td>MP 199.0-200.0 (7.47)</td></tr>
<tr><td colspan="2" rowspan="2">After (Aug. 2003 - Dec. 2004)</td><td>Section with the Highest Crash Rates</td><td>MP 197.0-198.0 (33.44)</td><td>MP 197.0-198.0 (53.51)</td></tr>
<tr><td>Section with the Lowest Crash Rates</td><td>The Other sections (0.00)</td><td>MP 200.0-200.51 (7.64)</td></tr>
<tr><td colspan="3">Section with the Largest Increase in Crash Rates From Before To After</td><td>MP 197.0-198.0 (29.65→33.44)</td><td>MP 199.0-200.0 (7.47→15.29)</td></tr>
<tr><td colspan="3">Section with the Largest Decrease in Crash Rates From Before To After</td><td>MP 198.0-199.0 (33.36 → 0.00)</td><td>MP 196.79-197.0 (33.36→15.29)</td></tr>
<tr><td colspan="6">Crash Analysis by Severity and Direction; Higher Severe Crash Rates (Crashes per 100 MVMT)</td></tr>
<tr><td rowspan="6"></td><td colspan="2" rowspan="2">Before</td><td>Broken Bones or Bleeding Blood (BBBB)</td><td>14.83</td><td>14.83</td></tr>
<tr><td>Fatal</td><td>0</td><td>3.71</td></tr>
<tr><td colspan="2" rowspan="2">During</td><td>Broken Bones or Bleeding Blood</td><td>0</td><td>7.47</td></tr>
<tr><td>Fatal</td><td>0</td><td>7.47</td></tr>
<tr><td colspan="2" rowspan="2">After</td><td>Broken Bones or Bleeding Blood</td><td>0</td><td>16.72</td></tr>
<tr><td>Fatal</td><td>0</td><td>8.36</td></tr>
</table>

Table C-20 summarizes the analysis results of other factors by direction on US 6. The directional crash rate analysis by severity and light condition during construction showed that ‘fatal’ and ‘broken bones or bleeding blood’ crashes happened in the ‘daylight’ light condition or ‘dark street or highway not lighted’ in the westbound direction. No ‘fatal’ and ‘broken bones or bleeding blood’ happened in the eastbound direction.

The directional crash rate analysis by analysis period and traffic control showed that the trends observed in the eastbound direction were similar to those in the westbound direction through the three analysis periods, except during construction. Before and after construction, the highest crash rates resulted in the 'traffic lane marked' traffic control. During construction, the highest rate was found in the 'traffic lanes marked' section in the eastbound direction, while the highest rate was found in the 'no control present' section in the westbound direction.

The directional crash rate analysis by analysis period and alignment showed that the trends in the relationship between alignment and the highest crash rates were very similar in both directions before and after construction but not during construction. The highest crash rates in both directions were found in the 'curve grade' sections before and after construction. The highest crash rates during construction were found in the 'straight and level' alignment in the eastbound direction and in the 'curve grade' alignment in the westbound direction.

The directional crash rate analysis by analysis period and weather condition showed that the weather conditions with the highest and lowest crash rates were the same in both directions before and after construction but not during construction. The weather condition with the highest crash rates was the 'snowing' condition before construction and the 'clear' condition after construction for both directions. During construction, the weather condition with the highest crash rates of both directions was the 'clear' condition.

The directional crash rate analysis by analysis period and surface condition showed that surface condition with the highest crash rates in both directions was in the 'dry' condition for the three periods.

The analysis of number of crashes by crash type during construction showed that the highest crash type in both directions was the 'MV-wild animal' type during construction, indicative of the rural wilderness setting of this work zone.

Table C-20 Summary of Other Analysis Results by Direction (US-6 Study Site)

Main Factor		Contents	Direction: Eastbound	Direction: Westbound
Monthly Crash Rate Analysis by Direction During Construction (Crashes per 100 MVMT)				
	Month with the Highest Crash Rates		Apr 2003 (16.86)	Apr 2002,May 2002, FeC. 2003 May 2003 (16.86)
	Month with the Lowest Crash Rates		May-Aug. 2002, Jan.-Mar. 2003, Jun-Aug.2003 (0.00)	Jul.2002, Sep.2002, Jan.2003, Jun.-Jul. 2003 (0.00)
Directional Crash Rate Analysis by Severity and Light Condition during Construction (Crashes per 100 MVMT)				
	Broken Bones or Bleeding Blood		0	Daylight (7.47)
	Fatal		0	Dark Street or Highway not Lighted (7.47)
Directional Crash Rate Analysis by Analysis Period and Traffic Control (Crashes per 100 MVMT)				
	Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (77.83)	Traffic Lanes Marked (96.36)
	Before	Traffic Control with the Lowest Crash Rates	Office or Watchman, No Passing Lanes (0.00)	No Passing Lanes (0.00)
	During	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (52.28)	No Control Present (97.09)
	During	Traffic Control with the Lowest Crash Rates	The Others Except Traffic Lane Marked, No Passing Lanes (0.00)	Office or Watchman, Slow or Warning Sign (0.00)
	After	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (66.88)	Traffic Lanes Marked (91.96)
	After	Traffic Control with the Lowest Crash Rates	The Others Except Traffic Lane Marked (0.00)	No Control Present, Office or Watchman (0.00)
	Traffic Control with the Largest Increase in Crash Rates From Before To After		-	No Passing Lanes (0.00 → 8.36)
	Traffic Control with the Largest Decrease in Crash Rates From Before To After		No Control Present (14.83 → 0.00)	No Control Present (29.65 → 0.00)
Directional Crash Rate Analysis by Analysis Period and Alignment (Crashes per 100 MVMT)				
	Before	Alignment with the Highest Crash Rates	Curve Grade (51.89)	Curve Grade (70.42)
	Before	Alignment with the Lowest Crash Rates	Curve Level (0.00)	Curve Level, Hillcrest Straight (0.00)
	During	Alignment with the Highest Crash Rates	Straight and Level (22.41)	Curve Grade (67.22)
	During	Alignment with the Lowest Crash Rates	Curve Level, Hillcrest Straight (0.00)	Curve Level, Hillcrest Straight (0.00)
	After	Alignment with the Highest Crash Rates	Curve Grade (25.08)	Curve Grade (41.80)
	After	Alignment with the Lowest Crash Rates	The Other Alignment Except Curve Grade, Grade Straight (0.00)	Curve Level, Curve Hillcrest, Hillcrest Straight (8.36)
	Alignment with the Largest Increase in Crash Rates From Before To After		-	Straight and Level (3.71→16.72)
	Alignment with the Largest Decrease in Crash Rates From Before To After		Curve Grade (51.89→25.08)	Curve Grade (70.42→41.80)

Table 4-20 Continued

<table>
<tr><th rowspan="2" colspan="2">Main Factor</th><th rowspan="2">Contents</th><th colspan="2">Direction</th></tr>
<tr><th>Eastbound</th><th>Westbound</th></tr>
<tr><td colspan="5">Directional Crash Rate Analysis by Analysis Period and Weather Condition (Crashes per 100 MVMT)</td></tr>
<tr><td rowspan="8"></td><td rowspan="2">Before</td><td>Weather Condition with the Highest Crash Rates</td><td>Snowing (44.48)</td><td>Snowing (63.01)</td></tr>
<tr><td>Weather Condition with the Lowest Crash Rates</td><td>Raining (0.00)</td><td>Raining, Windstorm (0.00)</td></tr>
<tr><td rowspan="2">During</td><td>Weather Condition with the Highest Crash Rates</td><td>Clear (29.87)</td><td>Snowing (44.81)</td></tr>
<tr><td>Weather Condition with the Lowest Crash Rates</td><td>Fog, Raining, Windstorm (0.00)</td><td>Fog, Raining, Windstorm (0.00)</td></tr>
<tr><td rowspan="2">After</td><td>Weather Condition with the Highest Crash Rates</td><td>Clear (16.72)</td><td>Clear (58.52)</td></tr>
<tr><td>Weather Condition with the Lowest Crash Rates</td><td>Cloudy, Fog, Windstorm (0.00)</td><td>Fog, Raining, Windstorm (0.00)</td></tr>
<tr><td colspan="2">Weather Condition with the Largest Increase in Crash Rates From Before To After</td><td>Raining (0.00 → 8.36)</td><td>Cloudy (11.12→16.72)</td></tr>
<tr><td colspan="2">Weather Condition with the Largest Decrease in Crash Rates From Before To After</td><td>Snowing (44.48 → 8.36)</td><td>Snowing (63.01 → 41.80)</td></tr>
<tr><td colspan="5">Directional Crashes Rate Analysis by Analysis Period and Surface Condition (Crashes per 100 MVMT)</td></tr>
<tr><td rowspan="8"></td><td rowspan="2">Before</td><td>Surface Condition with the Highest Crash Rates</td><td>Dry (40.77)</td><td>Dry (70.42)</td></tr>
<tr><td>Surface Condition with the Lowest Crash Rates</td><td>Wet (0.00)</td><td>Wet (3.71)</td></tr>
<tr><td rowspan="2">During</td><td>Surface Condition with the Highest Crash Rates</td><td>Dry (29.87)</td><td>Dry (67.22)</td></tr>
<tr><td>Surface Condition with the Lowest Crash Rates</td><td>Icy, Wet (7.47)</td><td>Wet (0.00)</td></tr>
<tr><td rowspan="2">After</td><td>Surface Condition with the Highest Crash Rates</td><td>Dry (16.72)</td><td>Dry (75.24)</td></tr>
<tr><td>Surface Condition with the Lowest Crash Rates</td><td>Icy (0.00)</td><td>Wet (0.00)</td></tr>
<tr><td colspan="2">Surface Condition with the Largest Increase in Crash Rates From Before To After</td><td>Wet (0.00→8.36)</td><td>Dry(70.42→75.24)</td></tr>
<tr><td colspan="2">Surface Condition with the Largest Decrease in Crash Rates From Before To After</td><td>Icy (22.24→0.00)</td><td>Icy (29.65→8.36)</td></tr>
<tr><td colspan="5">Analysis of the Number of Crashes by Crash Types during Construction (Number of Crashes Involved Crash Type/ Total Number of Crashes)</td></tr>
<tr><td></td><td colspan="2">The Highest Crash Type</td><td>MV-Animal (Wild) (4/8)</td><td>MV-Animal (Wild) (5/16)</td></tr>
</table>

C.1.5.3 Analyses by Construction Phase

Table C-21 summarizes the results of spatial and temporal analyses by construction phase on US 6. Among the three phases, Phase I had the longest construction time, while Phase II had the highest crash rates.

The temporal and spatial distribution analysis of crashes in the work zone by phase showed that the section from MP 197.0 to MP 198.0 had the highest crash rate in Phase I and Phase II, while the section from MP 198.0 to MP 199.0 had the highest crash rate in Phase III. The crash rate analysis by severity and phase found that ‘broken bones or bleeding blood’ and ‘fatal’ crashes happened only in Phase I.

The crash rate analysis by day of the week and phase showed that the occurrence of the highest crash rates was different by phase. Phase I had the highest crash percentage shared on Saturday, Phase II on Tuesday, Thursday, and Friday, and Phase III on Friday.

In the crash rate analysis by light condition and phase, the three phases had the highest crash rate in the ‘daylight’ or ‘dark street or highway not lighted’ condition. Also, the crash rate analysis by traffic control and phase showed that the highest crash rates were founded in the ‘traffic lanes marked’ control in all the three phases.

The crash rate analysis by alignment and phase showed that Phase I and Phase III had the highest crash rate in the ‘curve grade’ sections, while Phase II had the highest crash rate in the ‘straight and level’ sections.

The crash rate analysis by weather condition and phase showed that the weather conditions with the highest crash rate were different among the phases; the ‘snowing’ condition in Phase I, the ‘clear’ condition in Phase II, and the ‘cloudy’ condition in Phase III. The crash rate analysis by surface condition and phase showed that the highest crash rates were observed in the same surface condition, that is, the ‘dry’ condition for the three phases.

The analysis of crash breakdown type by phase showed that the crash types with high crash rates were the ‘MV-wild animal’ type in Phase I and II and the ‘MV-fixed object’ type in Phase III.

Table C-21 Summary of Spatial and Temporal Analysis Results by Construction Phase (US-6 Study Site)

Main Factor	Contents	Phase I	Phase II	Phase III
General Outline				
	Duration	Apr.2002-May2003	May2003-Jun.2003	Jun.2003-Jul.2003
	Main Construction Type	Widening	Rehabilitation	Chip Seal
	Crashes per 100 MVMT	211.13	392.1	130.7
Temporal Spatial Distribution of Crashes in Work Zone by Phase (Crashes per 100 MVMT)				
	Section with the Highest Crash Rates	MP 197.0-198.0 (80.43)	MP 198.0-199.0 (261.40)	MP 197.0-198.0 (137.70)
	Section with the Lowest Crash Rates	MP 199.0-200.0 (30.16)	MP 196.79-198.0, 200.0-201.51 (0.00)	The Other Sections (0.00)
Crash Analysis by Severity and Phase; Higher Severe Crash Rates (Crashes per 100 MVMT)				
	Broken Bones or Bleeding Blood (BBBB)	10.05	0	0
	Fatal	10.05	0	0
Crash Rate Analysis by Day of the Week and Phase (Crashes per 100 MVMT)				
	Day with the Highest Crash Rates	Saturday (60.32)	Tuesday, Thursday, Friday (130.70)	Friday (130.70)
	Day with the Lowest Crash Rates	Sunday(10.05)	Monday, Wednesday, Sunday (0.00)	The Other Days (0.00)
Crash Rate Analysis by Light Condition and Phase (Crashes per 100 MVMT)				
	Light Condition with the Highest Crash Rate	Dark Street or Highway Not Lighted (120.64)	Dark Street or Highway Not Lighted (261.40)	Daylight (130.70)
	Light Condition with the Lowest Crash Rate	Dark Street or Highway Lighted, Dawn, Dusk (0.00)	Dark Street or Highway Lighted, Dawn (0.00)	The Other Conditions (0.00)
Crash Rate Analysis by Traffic Control and Phase (Crashes per 100 MVMT)				
	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (170.91)	Traffic Lanes Marked (261.40)	Traffic Lanes Marked (130.70)
	Traffic Control with the Lowest Crash Rates	No Control Present, Office or Watchman, Slow or warning Sign (0.00)	Office or Watchman, Slow or warning Sign, No Passing Lanes (0.00)	The Other Control Methods (0.00)
Crash Rate Analysis by Alignment and Phase (Crashes per 100 MVMT)				
	Alignment with the Highest Crash Rates	Curve Grade (100.54)	Straight and Level (392.10)	Curve Grade (130.70)
	Alignment with the Lowest Crash Rates	Curve Level, Hillcrest Straight (0.00)	The Others (0.00)	The Others (0.00)
Crashes Rate Analysis by Weather Condition and Phase (Crashes per 100 MVMT)				
	Weather Condition with the Highest Crash Rates	Snowing (90.48)	Clear (261.40)	Cloudy (130.70)
	Weather Condition with the Lowest Crash Rates	Fog, Raining, Snowing, Windstorm (0.00)	Fog, Raining, Windstorm (0.00)	The Others (0.00)
Crash Rate Analysis by Surface Condition and Phase (Crashes per 100 MVMT)				
	Surface Condition with the Highest Crash Rates	Dry (100.54)	Dry (392.10)	Dry (130.70)
	Surface Condition with the Lowest Crash Rates	Wet (10.05)	The Others (0.00)	The Others (0.00)
Crash Breakdown Type by Phase (Number of Crashes Involved Crash Type/ Total Number of Crashes)				
	The Highest Crash Type	MV-Animal (Wild) (7/21)	MV-Animal (Wild) (2/3)	MV-Fixed Object (1/1)

C.1.5.4 Analyses for the Summer Months

Table C-22 summarizes the results of spatial and temporal analyses of the summer months on US 6. Data for June, July, and August from 1999 to 2004 were used. These summer months had the lowest crashes rates and the lowest crash rates by severity during construction. Note that no fatal crashes took place in the summer months in the three periods.

The crash rate analysis by severity for the summer months showed that 'broken bones or bleeding blood' crashes took place in all the three construction periods. However, the crash rates of the 'broken bones or bleeding blood' type increased after construction.

The spatial and temporal crash rate analysis in work zone for the summer months showed that the sections with the highest crash rates were from MP 197.0 to MP 198.0 before and after construction, and from MP 198.0 to MP 199.0 during construction.

The crash rate analysis by day of the week for the summer months showed that the highest crash rates were observed on Monday before construction, on Thursday and Friday during construction, and from Tuesday to Sunday after construction. The highest increase in crash rates from before to after construction was observed on Tuesday and Sunday, while the highest decrease in crash rates from before to after construction was observed on Monday.

Table C-22 Summary of Spatial and Temporal Analysis Results for the Summer Months (US-6 Study Site)

Main Factor			Contents
General Outline			
	Analysis Duration		June, July, Aug from 1999 to 2004
	Crash rates per 100 MVMT	Before	355.8
		During	196.96
		After	384.09
Crash Rate Analysis by Severity for the Summer Months (Crashes per 100 MVMT)			
	Before	Broken Bones or Bleeding Blood (BBBB)	44.48
		Fatal	0
	During	Broken Bones or Bleeding Blood	28.14
		Fatal	0
	After	Broken Bones or Bleeding Blood	115.19
		Fatal	0
Spatial and Temporal Crash Rate Analysis Work Zone for the Summer Months (Crashes per 100 MVMT)			
	Before	Section with the **Highest** Crash Rates	MP 197.0-198.0 (177.90)
		Section with the **Lowest** Crash Rates	MP 196.79-197.00, 199.0-200.0 (0.00)
	During	Section with the **Highest** Crash Rates	MP 198.0-199.0 (140.68)
		Section with the **Lowest** Crash Rates	MP 196.79 - 197.00, MP 200.0-200.51 (0.00)
	After	Section with the **Highest** Crash Rates	MP 197.0-198.0 (320.08)
		Section with the **Lowest** Crash Rates	MP 196.79 - 197.00, MP 199.01-200.51 (0.00)
	Section with **the Largest Increase in Crash Rate**s From Before To After		MP 197.0-198.0 (177.90→320.08)
	Section with **the Largest Decrease in Crash Rate**s From Before To After		MP 200.0-200.51 (88.95→0.00)
Crash Rate Analysis by Day of the Week for the Summer Months			
	Before	Day with the **Highest** Crash Rates	Monday
		Day with the **Lowest** Crash Rates	Tuesday, Sunday
	During	Day with the **Highest** Crash Rates	Thursday, Friday
		Day with the **Lowest** Crash Rates	Monday, Wednesday, Saturday, Sunday
	After	Day with the **Highest** Crash Rates	Tuesday-Sunday
		Day with the **Lowest** Crash Rates	Monday
	Day with **the highest Increase in Crash Rate**s From Before To After		Tuesday, Sunday
	Day with **the highest Decrease in Crash Rate**s From Before To After		Monday

Table C-23 summarizes the results of other analysis for the summer months such as light condition, traffic control, alignment, weather condition, surface condition, and involved crash type.

The crash rate analysis by light condition during construction for the summer months showed that the highest crash rates took place in the ‘dark street or highway not lighted’ condition before construction and the ‘daylight’ condition during and after construction. The lowest increase in crash rates happed in the ‘dark street or highway not lighted’ condition.

The crash rate analysis by analysis period and traffic control for the summer months showed that most of the crashes took place in the ‘traffic lanes marked’ sections in the three analysis phases.

The crash rate analysis by analysis period and alignment for the summer months showed that the ‘straight and always level’ sections had the highest crash rate during and after construction and the ‘curve grade’ sections had the highest crash rate before construction, while the ‘curve hillcrest’ sections and other sections had the lowest crash rates. After construction, the improvement in the ‘curve grade’ sections was achieved as shown in Table 4-24 resulting with the decrease in crash rates in the ‘curve grade’ sections.

The crash rate analysis by analysis period and weather condition showed that the highest crash rates were found in the ‘clear’ weather condition in the three construction phases. Also, the crash rate analysis by analysis period and surface condition showed that the highest crash rates took place in the ‘dry’ surface condition.

The analysis of the number of crashes by crash type during construction showed that among the crash types, crashes that involved ‘MV-wild animal’ type crashes had the highest number of crashes, 3 crashes out of a total of 7 crashes.

Table C-23 Summary of Other Analysis Results For the Summer Months (US-6 Study Site)

Main Factor		Contents
Crash Rate Analysis by Light Condition for the Summer Months (Crashes per 100 MVMT)		
Before	Light Condition with the Highest Crash Rates	Dark street or Highway Not Lighted (133.43)
	Light Condition with the Lowest Crash Rates	Dark street or Highway Lighted (0.00)
During	Light Condition with the Highest Crash Rates	Daylight (140.68)
	Light Condition with the Lowest Crash Rates	Dark street or Highway Lighted (0.00)
After	Light Condition with the Highest Crash Rates	Daylight (172.78)
	Light Condition with the Lowest Crash Rates	Dark street or Highway Lighted (0.00)
Light Condition with the Largest Increase in Crash Rates From Before To After		Daylight (88.95→172.78)
Light Condition with the Largest Decrease in Crash Rates From Before To After		Dawn (88.95→0.00)
Crash Rate Analysis by Traffic Control for the Summer Months (Crashes per 100 MVMT)		
Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (222.38)
	Traffic Control with the Lowest Crash Rates	Officer or Watchman (0.00)
During	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (140.68)
	Traffic Control with the Lowest Crash Rates	Officer or Watchman, Slow or warning Sign (0.00)
After	Traffic Control with the Highest Crash Rates	Traffic Lane Marked (287.97)
	Traffic Control with the Lowest Crash Rates	No Control Present, Officer or Watchman (0.00)
Traffic Control with the Largest Increase in Crash Rates From Before To After		No Passing lanes (0.00→57.51)
Traffic Control with the Largest Decrease in Crash Rates From Before To After		No Control Present (88.95→0.00))
Crash Rates by Alignment for the Summer Months (Crashes per 100 MVMT)		
Before	Alignment with the Highest Crash Rates	Curve Grade (177.90)
	Alignment with the Lowest Crash Rates	Curve Hillcrest, Curve Level, Hillcrest Straight (0.00)
During	Alignment with the Highest Crash Rates	Straight and Level (112.55)
	Alignment with the Lowest Crash Rates	Grade Straight, Curve Level, Hillcrest Straight (0.00)
After	Alignment with the Highest Crash Rates	Grade Straight (172.78)
	Alignment with the Lowest Crash Rates	Curve Hillcrest (0.00)
Alignment with the Largest Increase in Crash Rates From Before To After		Hill Straight, Curve Level (0.00→57.59)
Alignment with the Largest Decrease in Crash Rates From Before To After		Curve Grade (177.90→57.59)
Crashes Rate Analysis by Analysis Period and Weather Condition for the Summer Months (Crashes per 100 MVMT): No Changing (Clear and Cloudy)		
Crashes Rate Analysis by Analysis Period and Surface Condition for the Summer Months (Crashes per 100 MVMT): No Changing (Dry)		
Analysis of the Number of Crashes by Crash Types during Construction (Number of Crashes of the Crash Type/ Total Number of Crashes)		
The Highest Crash Type		MV-Animal (Wild) (3/7)

C.2 Case II: I-15 from MP 200.07 to MP 211.17, South of Nephi

C.2.1 General Analysis

C.2.1.1 Spatial and Temporal Crash Analysis

Like the Case I project, crashes within 5 miles upstream and downstream of the work zone were analyzed in order to find out the spatial and temporal characteristics of crashes. Crash rates per 100 MVMT by severity were determined for time and space. Figure C-30 shows the spatial and temporal trends of crashes by severity. These crash rates were computed for each 1 mile section either north or south of the work zone. For instance, ‘north 4 mile’ means the fourth one mile section from the north end of the work zone.

As shown in Figure C-30, the highest ‘no injury’ crash rate, 68.86 crashes per 100 MVMT, observed in the south 3 mile section in the before construction period. Actually, as crash rates fluctuated, some ‘no injury’ crash rates in some sections increased and those in other sections decreased. There were no ‘no injury’ crashes in some sections during construction, ‘south 2 mile’ and ‘south 1 mile’. In work zone, ‘no injury’ crash rates increased from before construction to during construction and decreased from during construction to after construction.

Except in the sections ‘south 3 mile’ and ‘north 1 mile’, ‘possible injury’ crash rates decreased or disappeared in all sections. One section, southbound 4 mile, didn’t have any crashes of ‘possible injury’. During construction, ‘possible injury’ crash rates decreased as time proceeded from before construction to after construction.

From ‘south 2 mile’ to ‘north 5 mile’, ‘bruises and abrasion’ crash rates decreased as time proceeded from the before and during construction periods to the after construction period. In the during construction period, some sections, ‘south 4 mile’, ‘south 3 mile’, and ‘north 4 mile’, didn’t have ‘bruises and abrasion’ crashes. The most increases in ‘bruises and abrasion’ were found in the ‘south 5 mile’ section. In the work zone, ‘bruises and abrasion’ crash rates were similar for the before, during, and after construction periods.

Except some sections, 'south 3 mile', 'south 2 mile', and 'north 2 mile', 'broken bones or bleeding blood' crash rates decreased after construction. From before construction period to during construction period, 'broken bones or bleeding blood' crash rates increased in southbound sections and decreased in northbound sections. This means that the southbound direction was more dangerous than the northbound direction during the construction period. In the work zone, 'broken bones or bleeding blood' crash rates deceased as time proceeded.

From 'south 3 mile' to 'north 3 mile', 'fatal' crashes took place in all three periods. 'Fatal' crashes took place in 'north 2 mile' and 'north 3 mile' sections during the before construction period. Both sections, two miles away from the work zone, had the highest 'fatal' crash rates during the during construction period. In the work zone, fatal crash rates increased as time proceeded from the before construction period to the during construction period and disappeared as time proceeded from the during construction period to the after construction period.

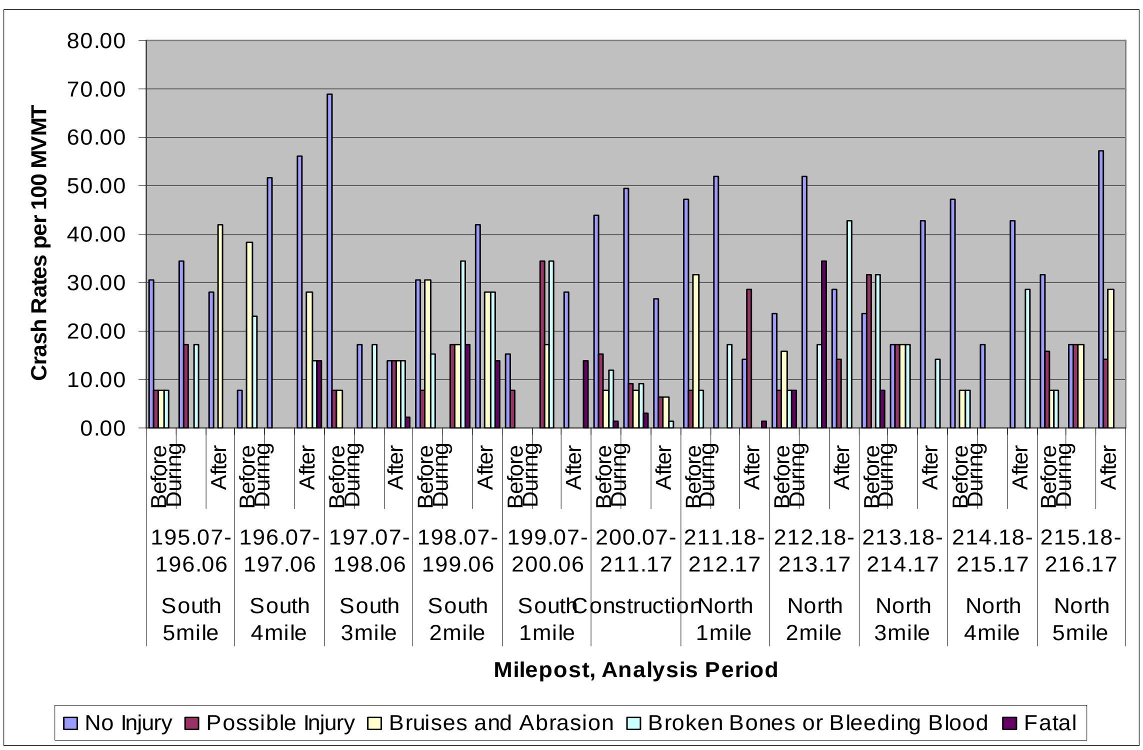

Figure C-30 Spatial and Temporal Crash Rate by Severity (I-15 Study Site)

Figure C-31 compares the spatial and temporal crash rate by milepost in the work zone. For the before and during construction periods, the mid-zone of the work zone had higher crash rates than the edges of the work zone; however, the edge sections in the after construction period had higher crash rates than the mid-section of the work zone

The section between MP 206.01 and MP 207.00 had the highest crash rates in the before construction period, the section between MP 208.01 and MP 209.0 during construction, and the section between MP 200.07 and MP 201.00 after construction.

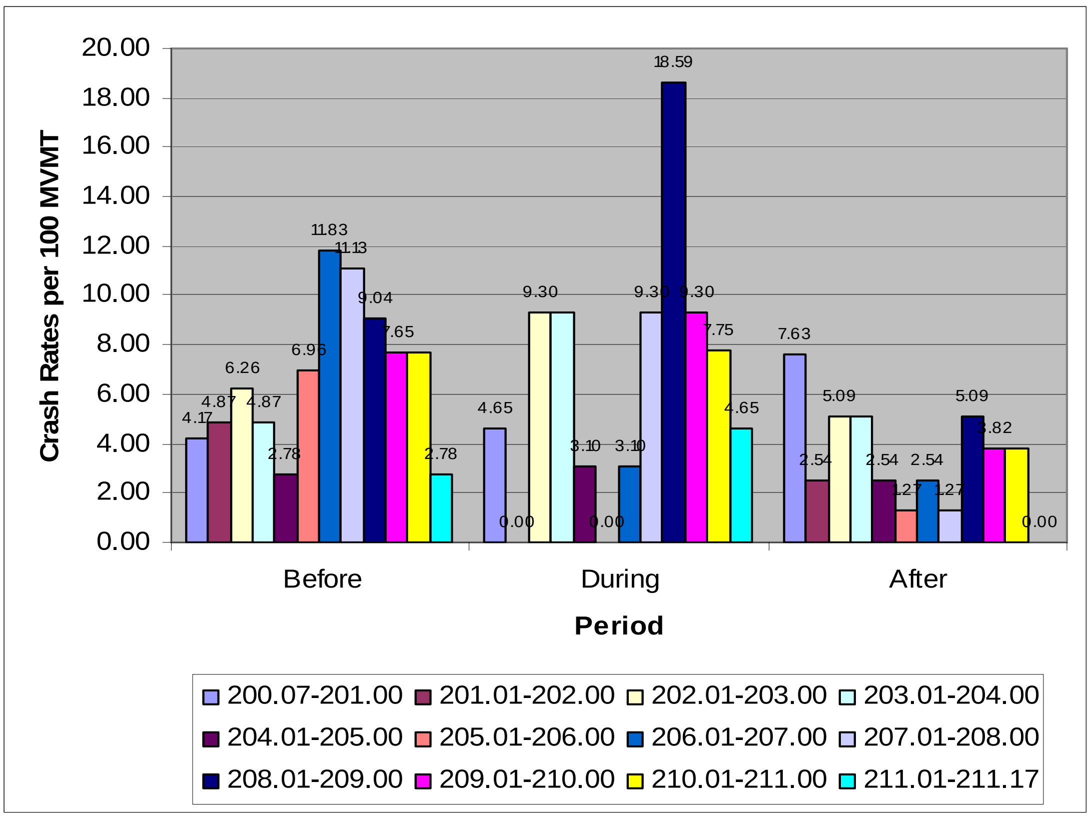

Figure C-31 Spatial and Temporal Crash Rate by Milepost in Work Zone (I-15 Study Site)

Figure C-32 shows monthly crash rates during construction. June of 2003 had the highest crash rate of 58.10 per 100 MVMT. At least one crash happed in each month. The early part and the end part of the construction period had higher crash rates than the mid part of the construction time.

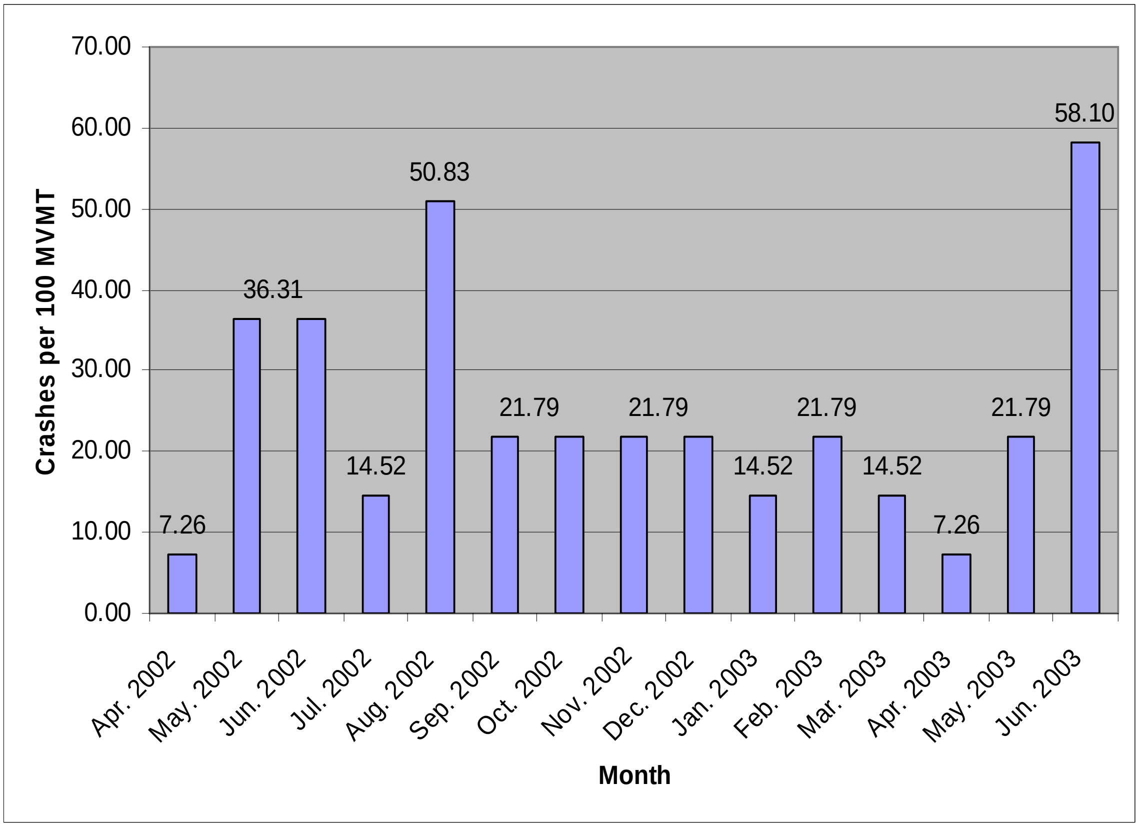

Figure C-32 Monthly Crash Rates during Construction (I-15 Study Site)

Figure C-33 shows percent distribution of crashes by day of the week and analysis period. The highest crash percentage fell on Sunday (20%) before construction, on Tuesday (22%) during construction, and on Saturday (28%) after construction. Crashes in percentages (34-35 %) during weekends for each analysis period were similar, but the distribution between Saturday and Sunday were different. Much of the changes happened on Tuesday and Sunday as time proceeded from the before, during and after construction periods.

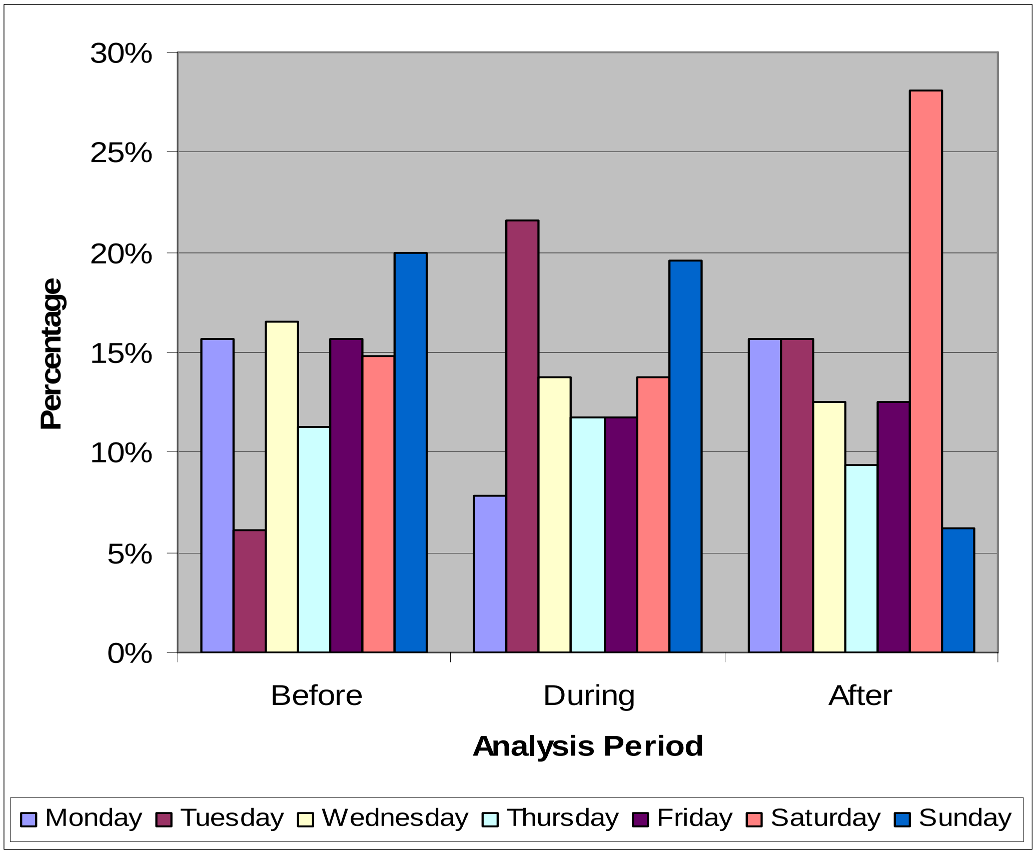

Figure C-33 Percent Distribution of Crashes by Day of Week and Analysis Period (I-15 Study Site)

Figure C-34 shows hourly distribution of the number of crashes during construction. The highest number of crashes took place in two hourly slots: 11:00-12:00 AM and 03:00-04:00 PM. AM and PM peak periods had a few more crashes than the other hourly time slots. The number of crashes in the afternoon was generally higher than the number of crashes in the morning. No crashes were at mid-night and 10:00 -11:00 AM during construction.

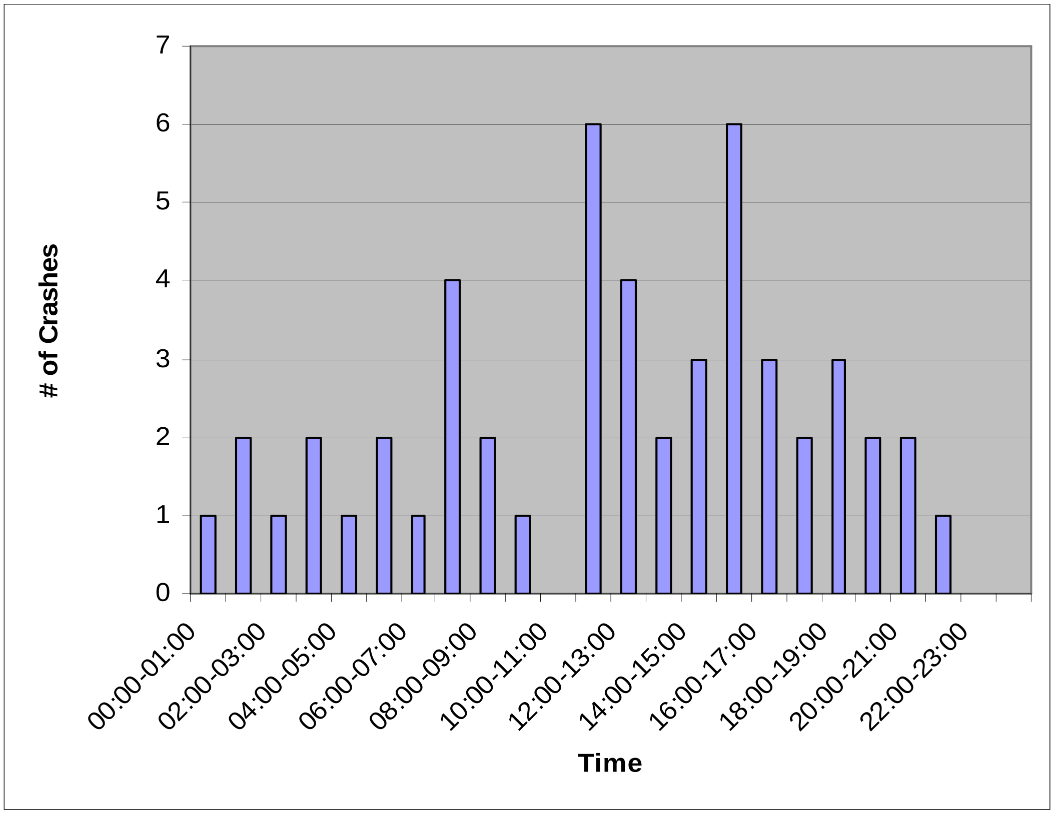

Figure C-34 Hourly Distribution of the Number of Crashes during construction (I-15 Study Site)

C.2.1.2 Other Analyses

Figure C-35 shows crash rates by light condition. Most crashes took place in 'daylight' and 'dark street or highway not lighted' conditions. The 'daylight' condition had the highest crash rate. The other conditions such as 'dawn', 'dusk', and 'dark street or highway lighted', had a few of crashes. After construction, crash rates in all conditions decreased or disappeared.

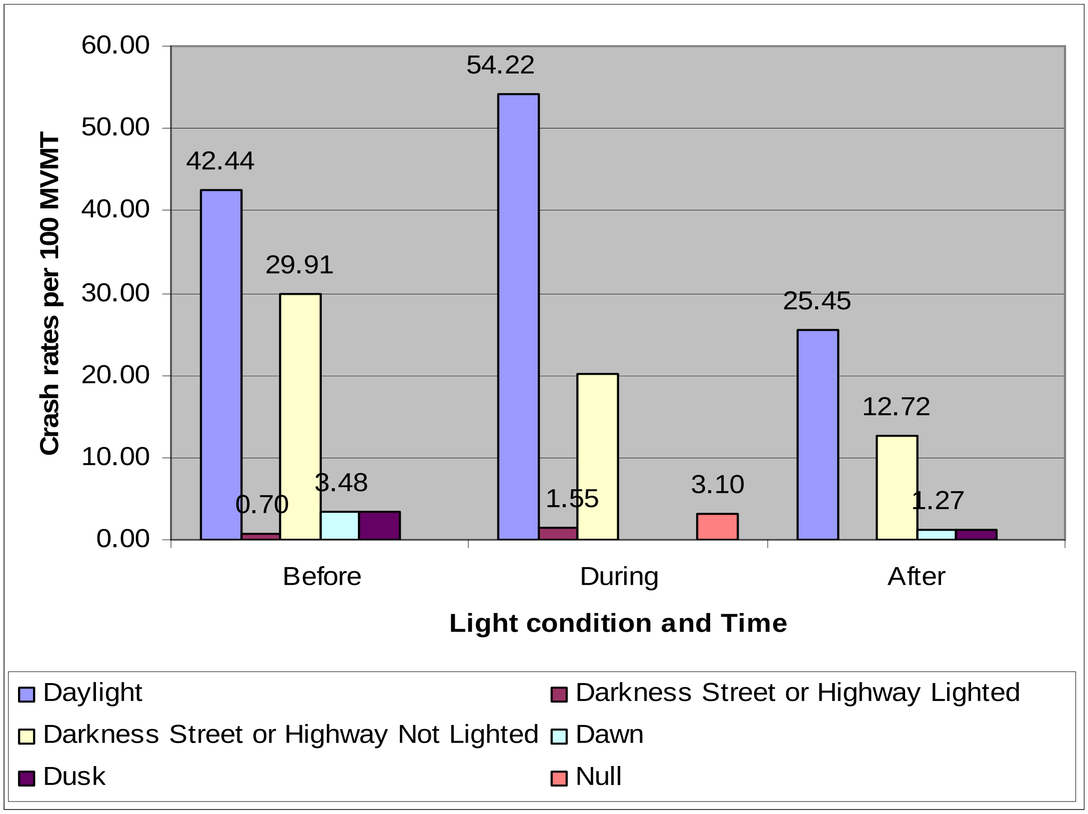

Figure C-35 Crash Rates by Light Condition (I-15 Study Site)

Table C-24 shows crash rates in 100 MVMT by crash severity level and light condition during construction. The 'daylight' condition had the highest crash rate, 57.32 crashes per 100 MVMT followed by the 'dark street or highway not lighted' condition, 20.14 crashes per 100 MVMT. All 'fatal' and 'broken bones or bleeding blood' crashes occurred in the 'dark street or highway not lighted' and 'daylight' conditions during construction. The majority of crashes that took place during construction in the work zone were 'no injury' crashes as shown in Table C-24.

Table C-24 Crash Rates by Severity and Light Condition during Construction (I-15 Study Site)

(Unit: Crashes per 100MVMT)

	No Injury	Possible Injury	Bruises and Abrasion	Broken Bones or Bleeding Blood	Fatal	Total
Daylight	32.53	9.30	6.20	7.75	1.55	57.32
Dark Street or Highway Lighted	1.55	0.00	0.00	0.00	0.00	1.55
Dark Street or Highway Not Lighted	15.49	0.00	1.55	1.55	1.55	20.14
Dawn	0.00	0.00	0.00	0.00	0.00	0.00
Dusk	0.00	0.00	0.00	0.00	0.00	0.00
Total	49.58	9.30	7.75	9.30	3.10	79.01

Figure C-36 shows crash rates by analysis period and traffic control, where crashes took place. Most crashes took place in locations identified as the 'traffic lanes marked', and 'construction or work area'. The highest crash rates happened in the 'traffic lanes marked' category in all three analysis periods.

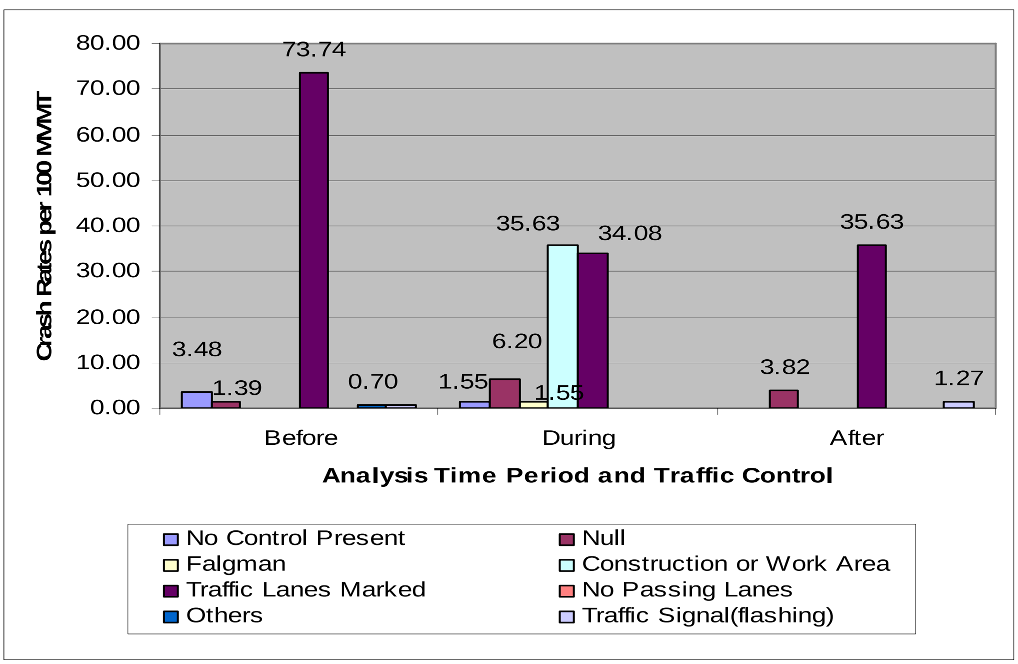

Figure C-36 Crash Rates by Analysis Period and Traffic Control (I-15 Study Site)

Figure C-37 shows crash rates by alignment for each analysis period. The highest crash rates were recorded in the 'straight and level' section in all three construction periods. While crash rates for the 'curve grade' and 'curve level' sections increased during and after construction, crash rates for the other alignment sections decreased both during and after construction. Crashes for the 'dip straight' section were newly recorded in the after construction period, while crashes for the 'hillcrest straight' section disappeared after construction.

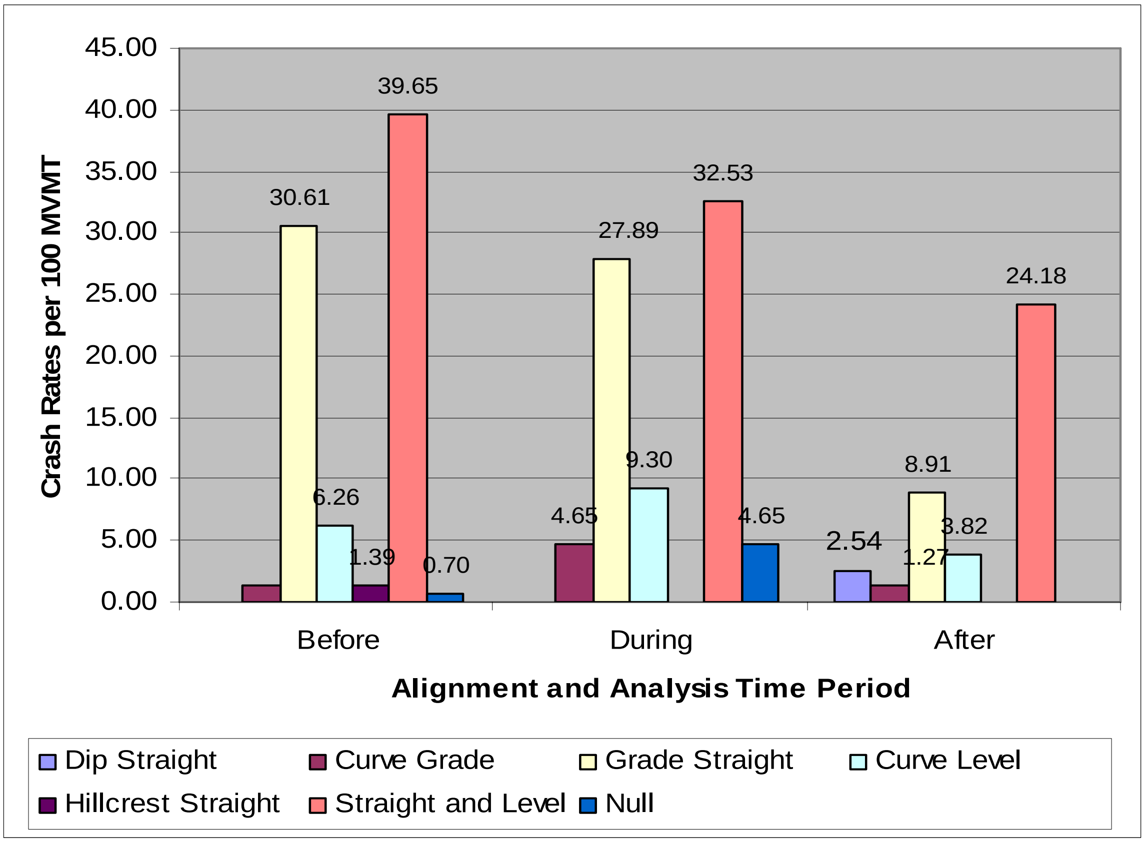

Figure C-37 Crash Rates by Analysis Period and Alignment Type (I-15 Study Site)

Table C-25 presents crash rates by weather condition and analysis period. Most of the crashes happened in the 'clear' and 'snowing' weather conditions. The crash rate in the 'cloudy' condition was higher during construction than before and after construction. The total crash rate before construction was higher than those during and after construction, and the total crash rate after construction was the lowest. This means that work was beneficial for improving traffic safety in this stretch of highway.

Table C-25 Crash Rate by Analysis Period and Weather Condition (I-15 Study Site)

(Unit: Crashes per 100MVMT)

	Before	During	After
Clear	48.00	46.48	25.45
Cloudy	10.44	15.49	10.18
Fog	0.00	0.00	0.00
Raining	4.87	1.55	0.00
Snowing	13.91	9.30	3.82
Sleeting	1.39	1.55	1.27
Mist	0.70	0.00	0.00
Null	0.70	4.65	0.00
Total	80.00	79.01	40.72

Figure C-38 shows crash rates by analysis period and surface condition. Most crashes happened on the ‘dry’ surface condition. Some crashes took place in surface conditions like ‘icy’, ‘snowy’, ‘wet’ and ‘muddy’ conditions. Crashes which happened in ‘dry’ and ‘snow’ condition during the construction period had higher crash rates than those in the before and after periods.

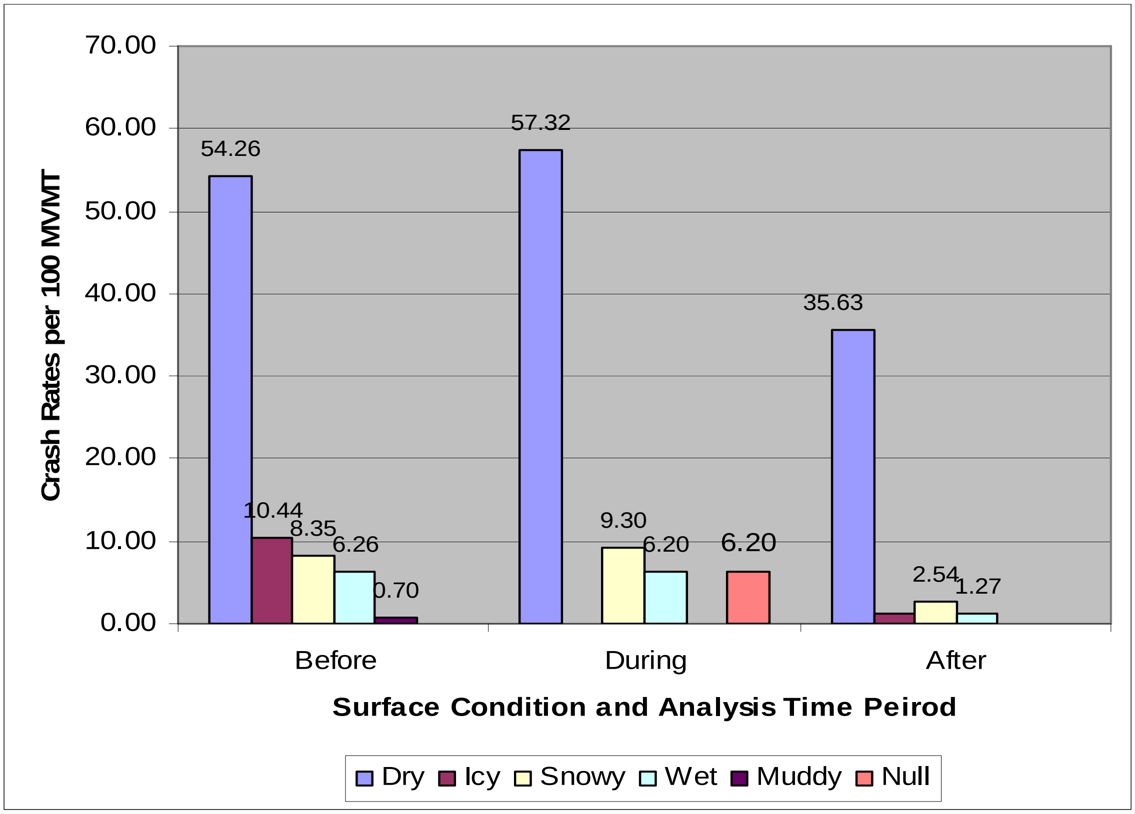

Figure C-38 Crash Rates by Analysis and Surface Condition (I-15 Study Site)

Table C-26 shows crash rate distribution by vehicle involvement. Crashes by vehicle involvement were divided into two groups, single vehicle and multi-vehicle (MV-MV). Over 67 percent of crashes involved single vehicles. The crash rates (33.0 percent) in the during construction period involved multi-vehicles, which were higher than those in the before and after construction periods. Some crashes in the after construction period involved backing crashes.

Table C-26 Crash Rates by Analysis Period and Vehicle Involvement (I-15 Study Site)

(Unit: Crashes per 100MVMT)

	Before	During	After
MV-MV	6.26	26.34	6.36
Single vehicle	73.74	52.67	33.08
Backing	0.00	0.00	1.27
Total	80.00	79.01	40.72

Table C-27 shows the number of crashes by crash type during construction in the work zone. Thirty-one percent of crashes were related to the 'MV-MV' crash type. Crash types like 'Ran-off Roadway-Right', 'Ran Off Roadway-Left' and 'MV-Fixed Objects' together occupied 52 percent of the total number of crashes. All other types had only one crash during construction.

Table C-27 Number of Crashes by Crash Types during Construction (I-15 Study Site)

Number of Vehicle	Accident Type	#of Crashes
Single Vehicle	MV-Animal(Domestic)	1
	MV-Animal(Wild)	1
	MV-Fixed Object	5
	MV-Other Object	3
	Ran Off Roadway-Left	7
	Ran Off Roadway-Right	12
	Ran Off Roadway-Thru Median	3
	Other Non-Collision	1
	Overturned	1
MV-MV	MV-MV	16
	MV-MV(Other Objects)	1
Total		51

C.2.2 Directional Analysis

C.2.2.1 Outline

The annual number of crashes and crash rates per 100 MVMT in the 'northbound' direction were similar to those in the southbound direction for before, during and after construction, as shown in Table C-28. Before construction, the crash rates of the 'northbound' and the 'southbound' directions were 38.96 crashes per 100 MVMT and 41.04 crashes per 100 MVMT. During construction, the crash rates of the 'northbound' and the 'southbound' directions were 37.18 crashes per 100 MVMT and 38.73 crashes per 100 MVMT. Also, during construction, there were some crashes without exact direction, which will be ignored in subsequent analyses because the crash rate of this category was small. After construction, the crash occurrences in the 'northbound' direction and 'southbound' direction were the same at 20.36 crashes per 100 MVMT.

The analysis period of before, during, and after construction are the same as that of the General Outline, i.e., 3 years, 15 months, and 18 months, respectively.

Table C-28 Summary of Directional Crashes (I-15 Study Site)

	Before			During			After		
	#of Crashes	Annual average	Crash Rates per 100MVMT	#of Crashes	Annual average	Crash Rates per 100MVMT	#of Crashes	Annual average	Crash Rates per 100MVMT
North	56.00	18.67	38.96	24.00	19.20	37.18	16.00	10.67	20.36
South	59.00	19.67	41.04	25.00	20.00	38.73	16.00	10.67	20.36
Null	0.00	0.00	0.00	2.00	2.00	3.87	0.00	0.00	0.00
Total	115.00	38.33	80.00	51.00	41.20	79.79	32.00	21.33	40.72

C.2.2.2 Spatial and Temporal Crash Analysis

Figure C-39 shows spatial and temporal crash distribution of crash data by direction and analysis period. Crash rates in the mid-section of the work zone were higher than those in the end sections in the before and during construction periods. However, after construction, crash rates in the ends sections of the work zone became higher than those in the mid-section of the work zone. Also, after construction, crash rates decreased in both directions, which meant that traffic safety conditions were improved by the work.

In the northbound direction, the highest crash rate was recorded at a section between MP 206.01 and MP 207.00 before construction, a section between MP 208.01 and MP 209.00 during construction, and sections between MP 200.07 and MP 201.00 and between MP 208.01 and MP 209.00 after construction. During construction, crashes were concentrated in a few end sections.

In the southbound direction, sections with high crash rates were located between MP 206.01 and MP 208.00 before construction, between MP 207.01 and MP 209.00 during construction, and between MP 202.01 and MP 203.00 and between MP 210.01 and MP 211.00 after construction. During and after construction, crashes were concentrated in a few end sections.

The trends of crash distribution in both directions were similar before and during construction, but different after construction. After construction, crashes in the north direction were distributed out from the work zone, while crashes in the southbound direction were concentrated on the end sections of the work zone.

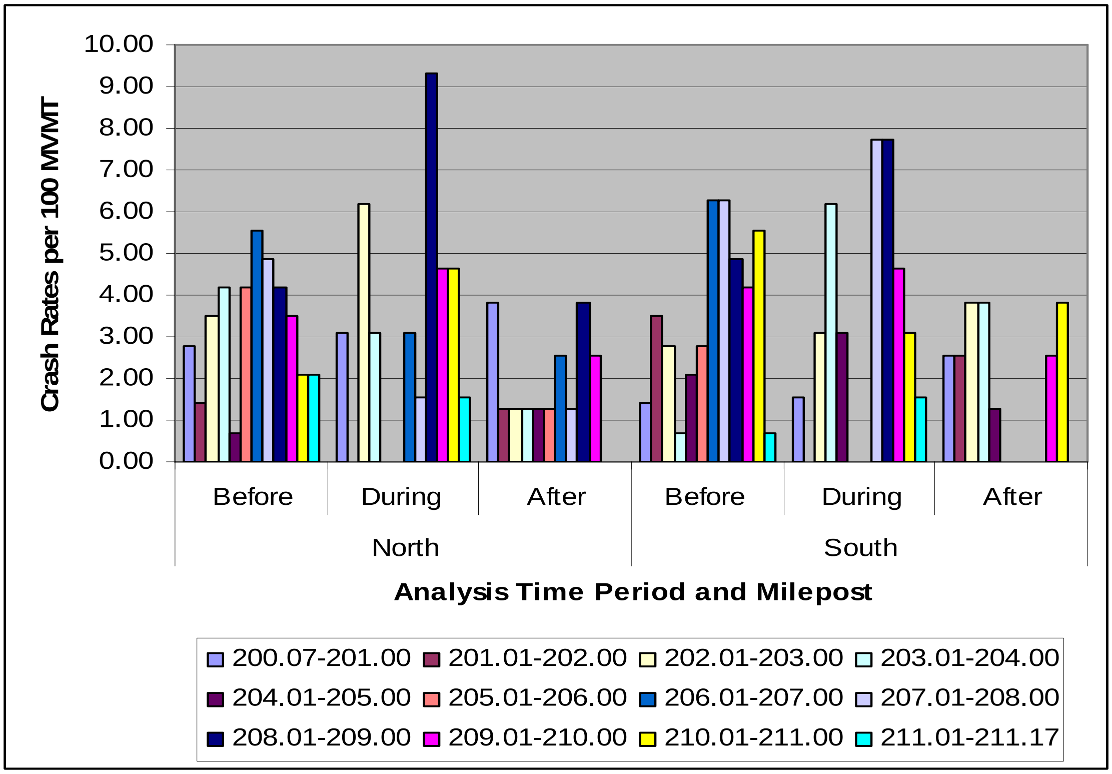

Figure C-39 Spatial and Temporal Distribution of Crash Rates by Direction and Analysis Period (I-15 Study Section)

As shown in Figure C-40, the northbound direction had higher crash rates than the southbound direction. The severity type of high crash rates of every analysis period in both directions was ‘no injury’ crashes. ‘Fatal’ crashes took place in both directions before and during construction. All crash severity types decreased after construction.

‘Fatal’ crash rates increased from 0.70 to 1.55 crashes per 100 MVMT during construction. In the northbound direction, ‘broken bones or bleeding bones’ crash rates decreased from 4.87 crashes per 100 MVMT before construction, to 1.55 crashes per 100 MVMT during construction, to 1.27 crashes per 100 MVMT after construction. In the southbound direction, ‘broken bones or bleeding bones’ crash rates decreased from 6.96 crashes per 100 MVMT before construction, to 6.20 crashes per 100 MVMT during construction, to 0.00 crashes per 100 MVMT after construction. This reduction indicated that traffic safety conditions improved after construction.

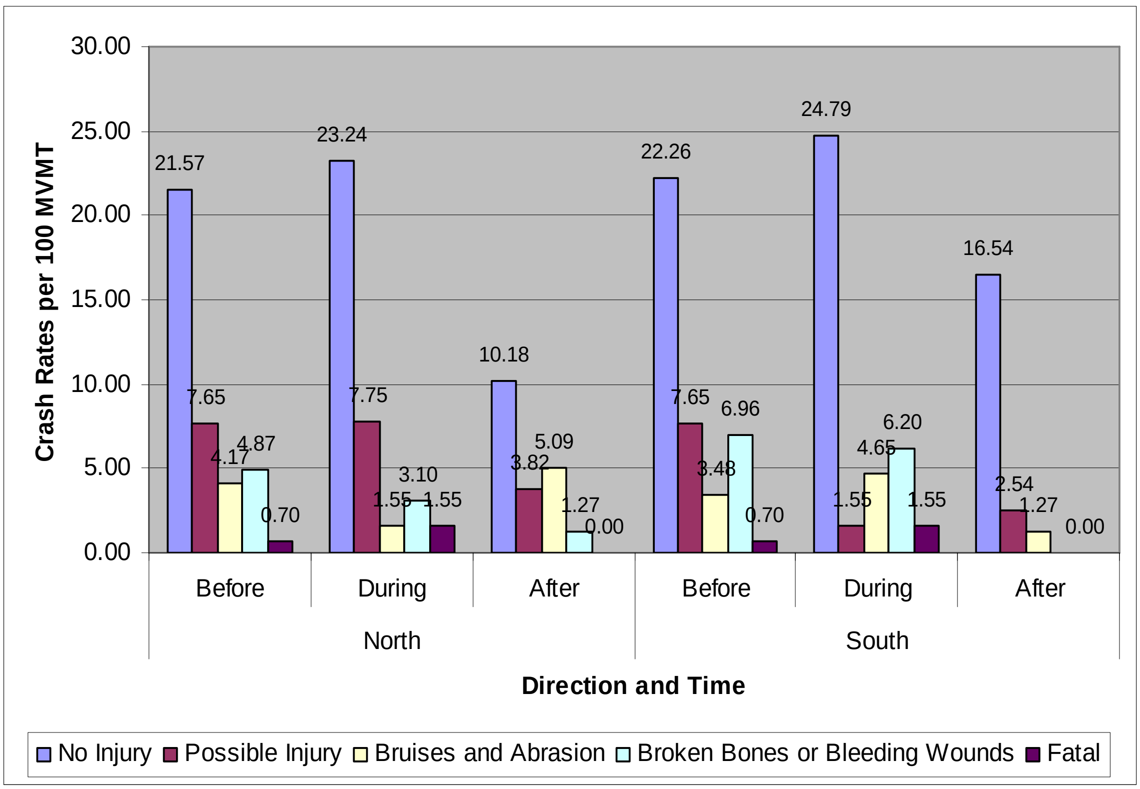

Figure C-40 Directional Distribution of Crash Rates by Analysis Period and Severity (I-15 Study Site)

Figure C-41 shows a monthly crash rate distribution by direction. This figure shows different monthly distribution patterns in crash occurrence, but the overall crash rates during construction for the two directions were similar as seen in Table C-28. In both directions, the end sections of the work zone had higher crash rates than the middle part of the construction period. The highest crash rates, 6.20

crashes per 100 MVMT in both directions took place in June of 2003, which is the last month of construction period. Crashes in the northbound direction were concentrated in the early and last months of the construction period, while those in the southbound direction were concentrated in the early months, the mid-months, and the last month of the construction period. No crashes happened in July of 2002 and March of 2003 for the northbound direction, and in April of 2002 and January and March of 2003 for the southbound direction.

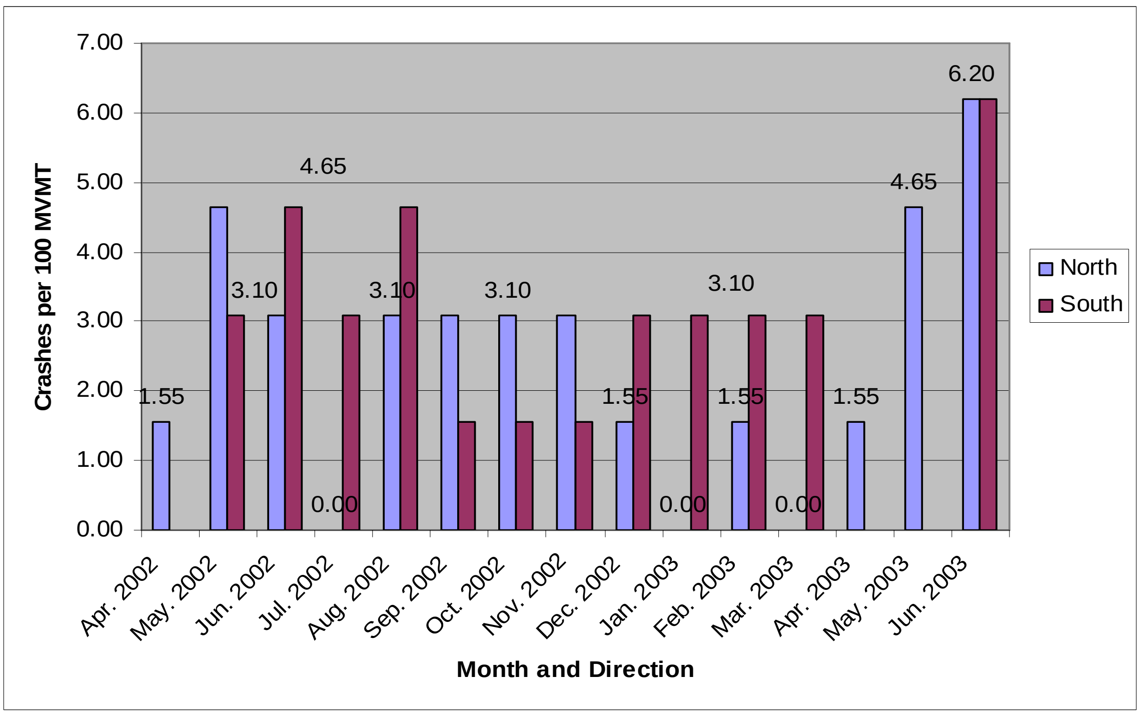

Figure C-41 Monthly Crash Rate Distribution by Direction during Construction (I-15 Study Site)

Table C-29 shows crash rates for both northbound and southbound directions by severity and light condition. Most crashes happened in the 'daylight' and 'dark street or highway not lighted' conditions. Severe crashes were concentrated in the 'daylight' and 'dark street or highway not lighted' conditions in both directions.

Table C-29 Directional Crash Rates by Severity and Light Condition (I-15 Study Site)

(Unit: Crashes per 100MVMT)

Direction	No Injury		Possible Injury		Bruises and Abrasion		Broken Bones or Bleeding Blood		Fatal		Total
	North	South	North	South	North	South	North	South	North	South	
Daylight	16.70	16.70	8.35	1.67	0.00	5.01	3.34	5.01	1.67	0.00	58.44
Darkness Street or Highway Lighted	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67
Darkness Street or Highway Not Lighted	8.35	8.35	0.00	0.00	1.67	0.00	0.00	1.67	0.00	1.67	21.71
Dawn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dusk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	25.04	26.71	8.35	1.67	1.67	5.01	3.34	6.68	1.67	1.67	81.81

Figure C-42 shows crash rates by traffic control for the northbound and southbound directions, and by analysis period. In both directions, high crash rates were recorded in the 'traffic lanes marked' type except during construction in the northbound direction. In both directions, many crashes happened in the 'construction or work area' and 'flagman' traffic control during construction. In both directions, more crash types were observed before and during construction than after construction. This means that the work zone had a positive effect on traffic safety in this section.

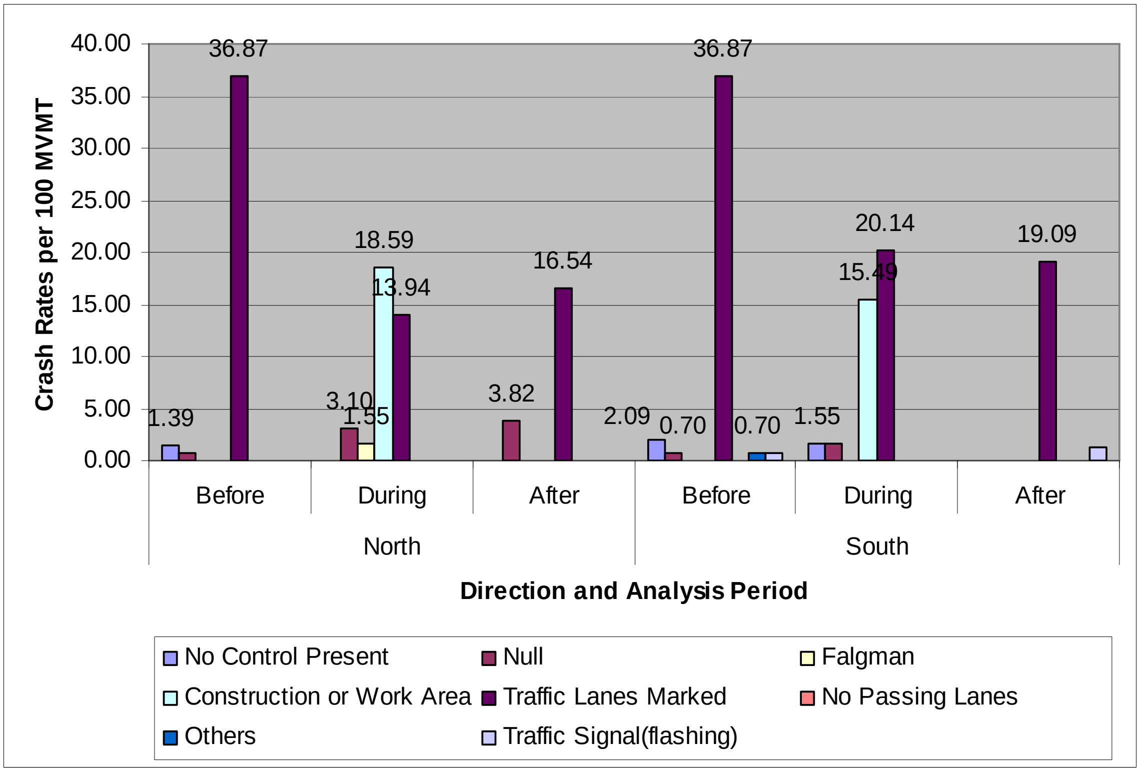

Figure C-42 Directional Crash Rate Distribution by Traffic Control and Analysis Period (I-15 Study Site)

Figure C-43 shows directional distribution of crashes in percentage by day of the week and analysis period. Crash occurrences by day of the week were somewhat different between the two directions.

In the northbound direction, the percent share of Tuesday and Saturday increased dramatically after construction, while the percent share of Thursday and Sunday decreased sharply after construction. The highest percent share was on Sunday before construction, Tuesday during construction, and Saturday after construction, respectively.

In the southbound direction, the percent share of Saturday increased dramatically after construction. The percent share of Friday decreased after construction. The highest percent share was on Wednesday and Friday before construction, Sunday during construction, and Saturday after construction.

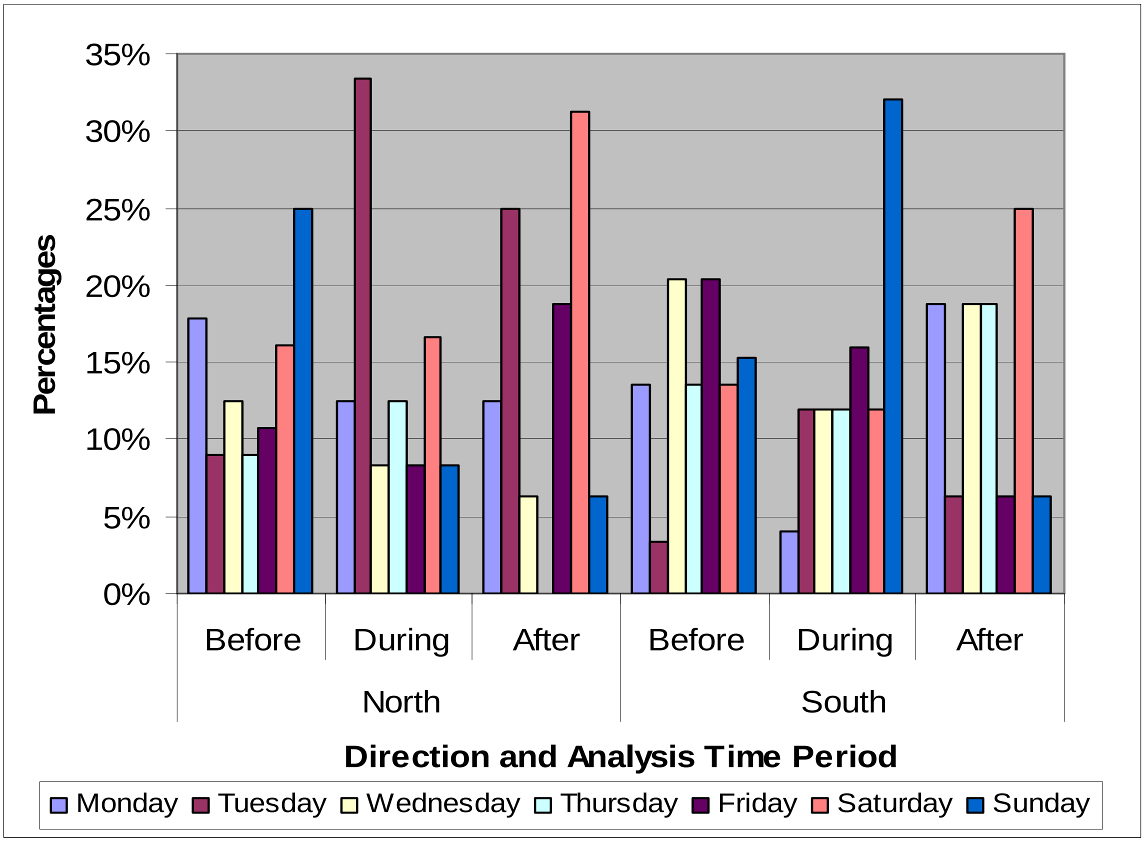

Figure C-43 Directional Distribution of Crashes in Percentage by Day of the Week and Analysis Period (I-15 Study Site)

Figure C-44 shows directional distribution of crashes by alignment type and analysis period. Generally, there were serious safety problems in the 'straight and level' and 'curve grade' sections. Crash rates of the 'straight and level' section increased in both directions during construction. Crash rates in all alignment conditions decreased in both directions after construction except in the 'curve grade' section

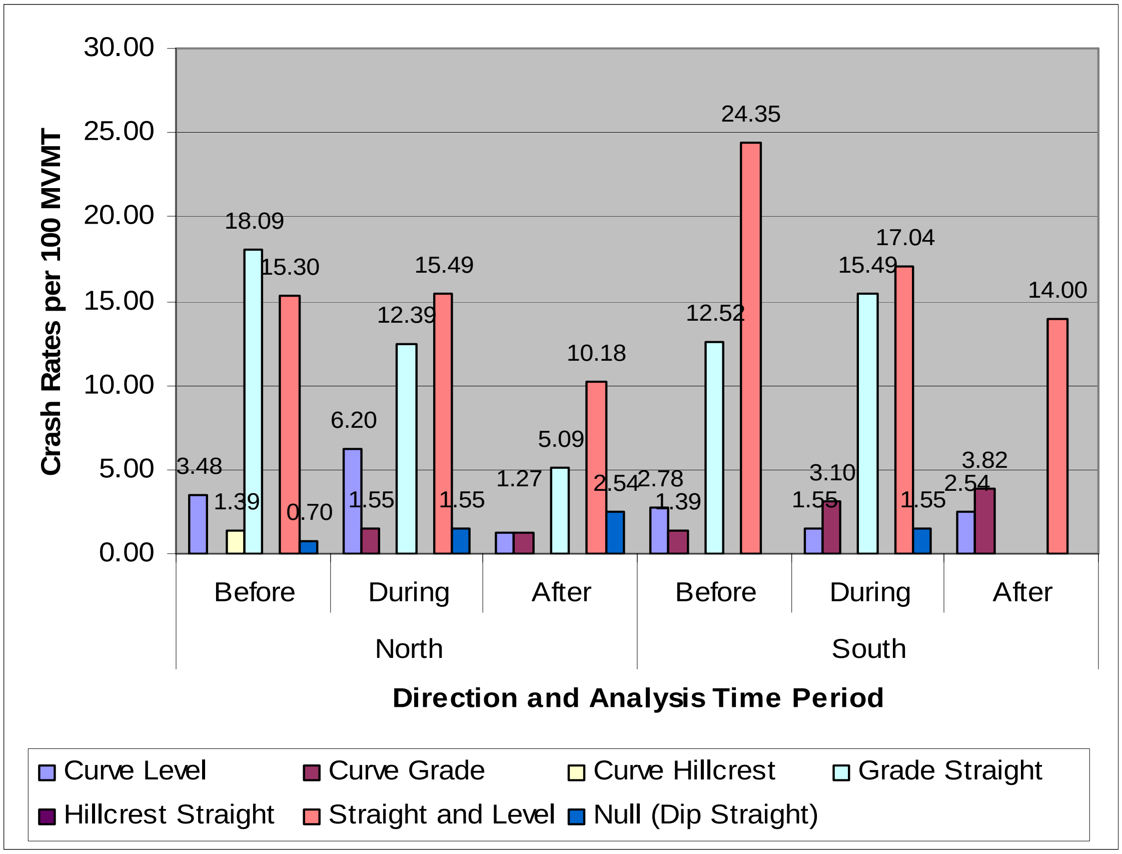

Figure C-44 Directional Distribution of Crashes by Alignment and Analysis Period (I-15 Study Site)

Figure C-45 shows directional distribution of crash rates by weather condition and analysis period. Crash rates were the highest in the 'clear' weather condition in both directions and through all analysis periods.

In the northbound direction, crashes took place in the 'cloudy' and 'snowing' condition before construction. As time proceeded from the before period to the after period, crashes in the 'cloudy' condition mildly increased. Other weather conditions like as 'raining' and 'sleeting' also affected crash occurrence but at lower rates.

In the southbound direction, the second two highest weather conditions that affected crashes were the 'cloudy' and 'snowing' conditions. During construction, crash rates increased in the 'cloudy' condition more than before construction. Other weather conditions like as 'raining', 'mist', and 'sleeting' also affected crashes, but at lower rates.

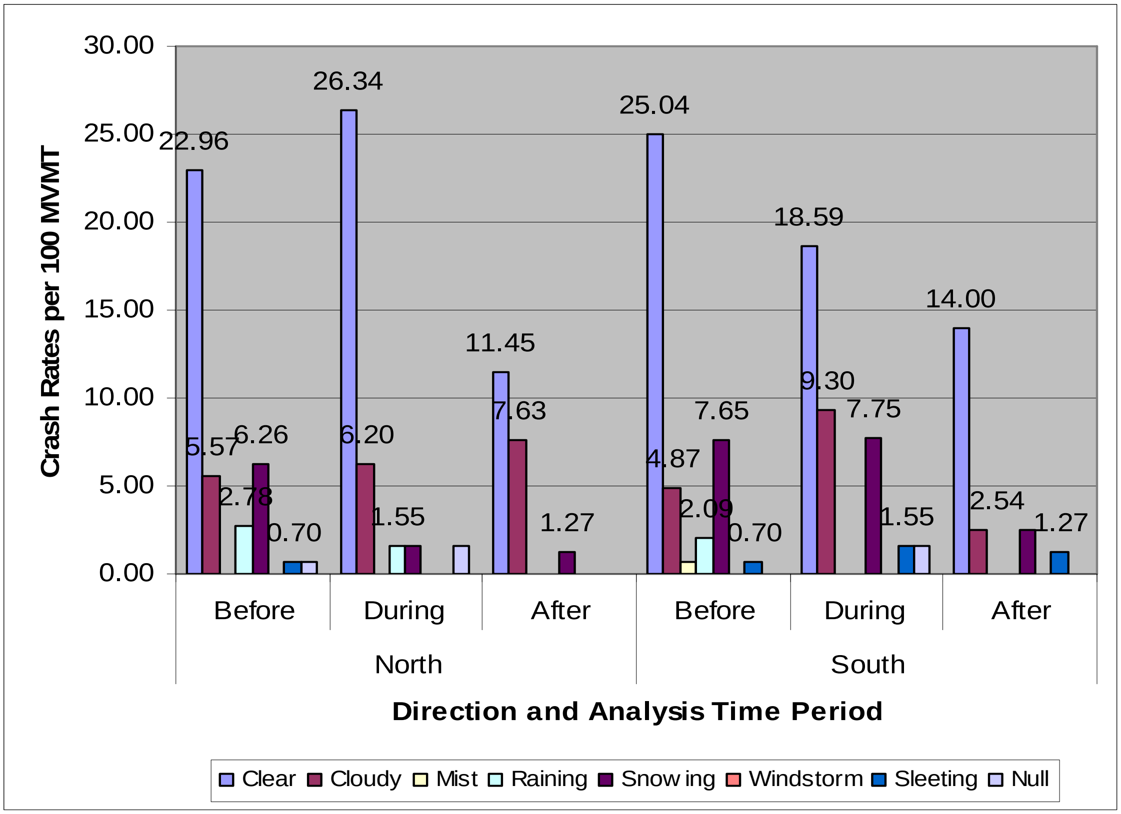

Figure C-45 Directional Distribution of Crash Rates by Weather Condition and Analysis Period (I-15 Study Site)

Pavement surface condition is closely related with the weather condition. Figure C-46 shows directional distribution of crash rates by surface condition and analysis period. In general, crash rates were high for the 'dry' condition in both directions. Cash rates by surface condition in general decreased as analysis period proceeded from before to after construction. Generally the 'dry' pavement condition had the highest crash rates in both directions.

In both directions, more crashes were recorded in the 'icy' condition before construction than compared to during and after construction. In the southbound direction, some crashes took place in the 'snowy' condition.

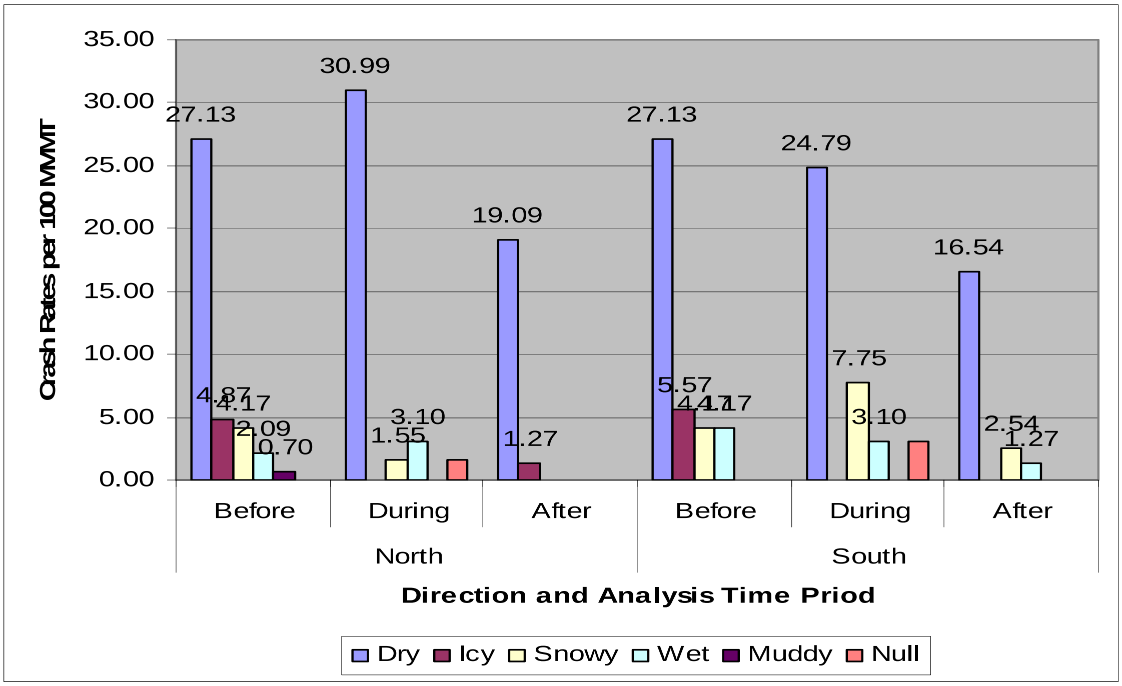

Figure C-46 Directional Distribution of Crash Rates by Surface Condition and Analysis Period (I-15 Study Site)

Table C-30 shows crash rates by involvement type for the three time periods for both directions. Crashes involving a 'single vehicle' more frequently occurred than those involving 'multiple vehicles' ('MV-MV'). More than two-thirds of crashes were 'single vehicle' crashes in all periods and directional contributions. There were higher crash rates of 'MV-MV' collision type during construction than before and after construction in both directions.

Table C-30 Crash Rates by Involvement Type (I-15 Study Site)

(Unit: Crashes per 100MVMT)

	North			South		
	Before	During	After	Before	During	After
MV-MV	2.78	12.39	2.54	3.48	13.94	3.82
Single vehicle	36.18	24.79	17.81	37.57	24.79	16.54
Total	38.96	37.18	20.36	41.04	38.73	20.36

*: MV: Multi-Vehicles

Table C-31 shows crash type breakdown by direction during construction. In both directions, the crash type of the highest frequency was the 'MV-MV'. In the northbound direction, four crash types were recorded, which were ‘MV-fixed objects’, ‘ran off roadway-left’, ‘ran off roadway-right’, and ‘MV-MV’. More crash types were recorded in the southbound direction.

Table C-31 Crash Type Breakdown by Direction during Construction (I-15 Study Site)

(Unit: Number of crashes)

During	Accident Type	North	South	Total
Single Vehicle	MV-Animal(Wild)	0	2	2
	MV-Fixed Object	4	1	5
	MV-Other Object	1	2	4
	Ran Off Roadway-Left	5	2	7
	Ran Off Roadway-Right	6	5	12
	Other Non-Collision	0	1	1
	Ran Off Roadway-Thru Median	1	2	3
	Overturned	0	1	1
MV-MV	MV-MV	7	9	16
	MV-MV(Ran Off Roadway-Right)	0	0	0
Total		24	25	51

C.2.3 Analysis by Construction Phase

C.2.3.1 Outline

The construction work at this study site was divided into three phases. The duration of phase I was 4.4 months from April of 2002 to August of 2003. Phase II was 3.3 months from August of 2003 to November of 2002. Phase III was 7.3 months from November of 2002 to June of 2003. Inside lane construction was the main work for phase I, dynamic compaction for phase II, and inside lane construction for phase III.

Crash rates in each phase were: 73.94 crashes per 100 MVMT for phase I, 98.59 crashes per 100 MVMT for phase II, and 73.22 crashes per 100 MVMT for phase III. Phase II had the highest crash rate among the three phases. Table C-32 provides basic information for each construction phase of this study site. Note that the reader must keep in mind that phase III covered the longest period, while phase I and III covered only three or four months.

Table C-32 Phase Information (I-15 Study Site)

Phase	Phase I	Phase II	Phase III
Time	04/01/02 -08/13/02	08/14/02-11/21/02	11/22/02-06/30/03
During (months)	4.4	3.3	7.3
Main Construction Type	Inside Lane Construction	Dynamic Compaction	Inside Lane Construction
# of Crashes	14	14	23
Annual Average	38.18	50.91	37.81
Crash Rates (per 100MVMT)	73.94	98.59	73.22

C.2.3.2 Spatial and Temporal Crash analysis

Figure C-47 shows spatial distribution of crashes in the work zone by construction phase. The trends of crash rates are different according to each phase. In Phase I and Phase II, crashes were concentrated in both ends of work zone, while crashes in Phase III were concentrated on the northern end of the work zone. Also, crash rates in Phase II and Phase III were higher than those in Phase I.

The highest crash rate section was between MP 207.01 and MP 208 in Phase I, and between MP 211.01 and MP 211.17 in Phase II and Phase III. In all phases, the mid- section of the work zone had the lowest crash rate.

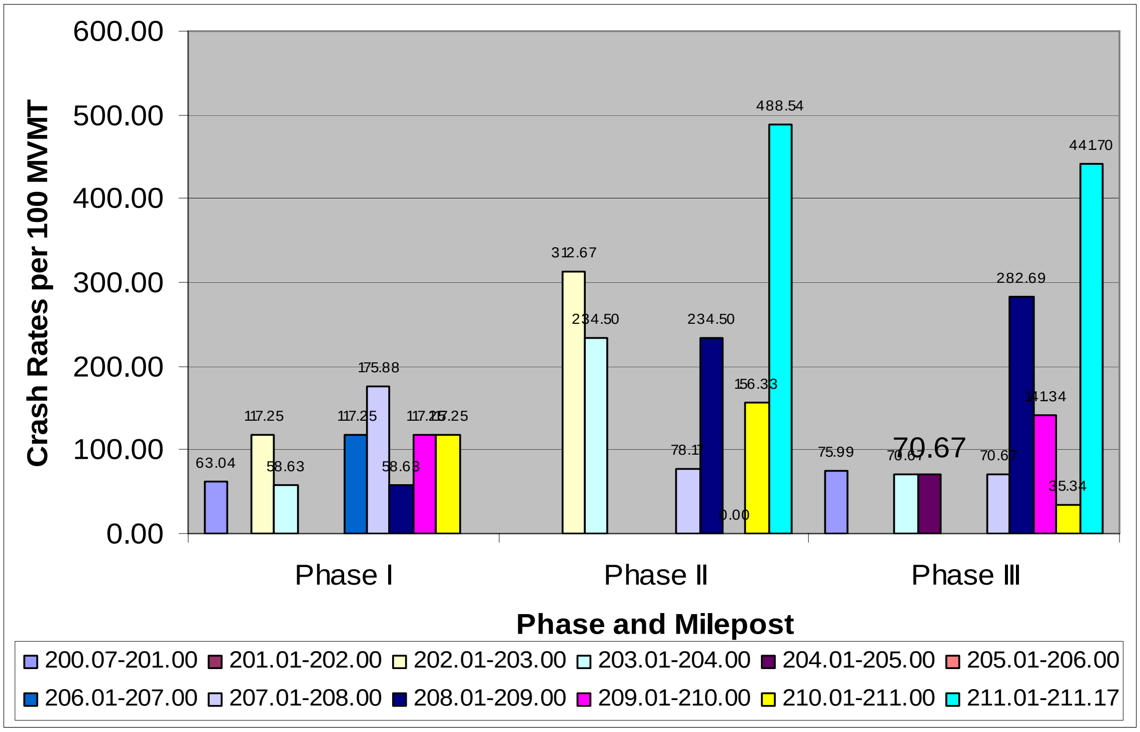

Figure C-47 Spatial Distribution of Crashes in the Work Zone by Phase (I-15 Study Site)

Figure C-48 shows crash rates by severity and construction phase. Most crashes were 'no injury' crashes in all phases. Among the three phases, Phase III had the most dangerous construction duration. The highest 'broken bones or bleeding blood' crash rates were in Phase III and 'fatal' crashes happened only in Phase III. Phase II in crash severity followed Phase III.

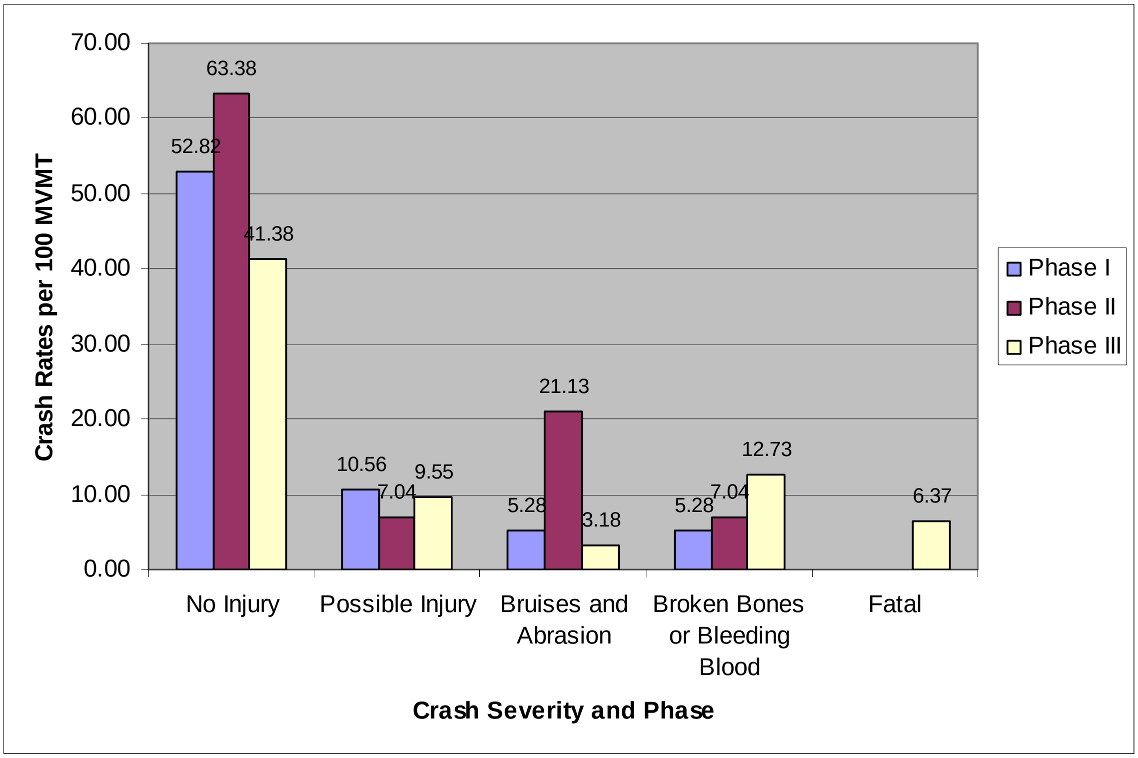

Figure C-48 Crash Rates by Severity and Phase (I-15 Study Site)

Figure C-49 shows the distribution of crashes by day of the week and construction phase. The distribution of crashes by day of the week was different in each phase. In Phase I and Phase III, the crashes took place in the early part of weekday and weekends. In Phase II, crashes were concentrated during the mid-weekday. Tuesday had the highest distribution in Phase I, Thursday in Phase II, and Sunday in Phase III. There were no crashes on weekends in Phase II, Wednesday in Phase I and Thursday in Phase III. However, it is difficult to pinpoint direct contributing causes from the available records.

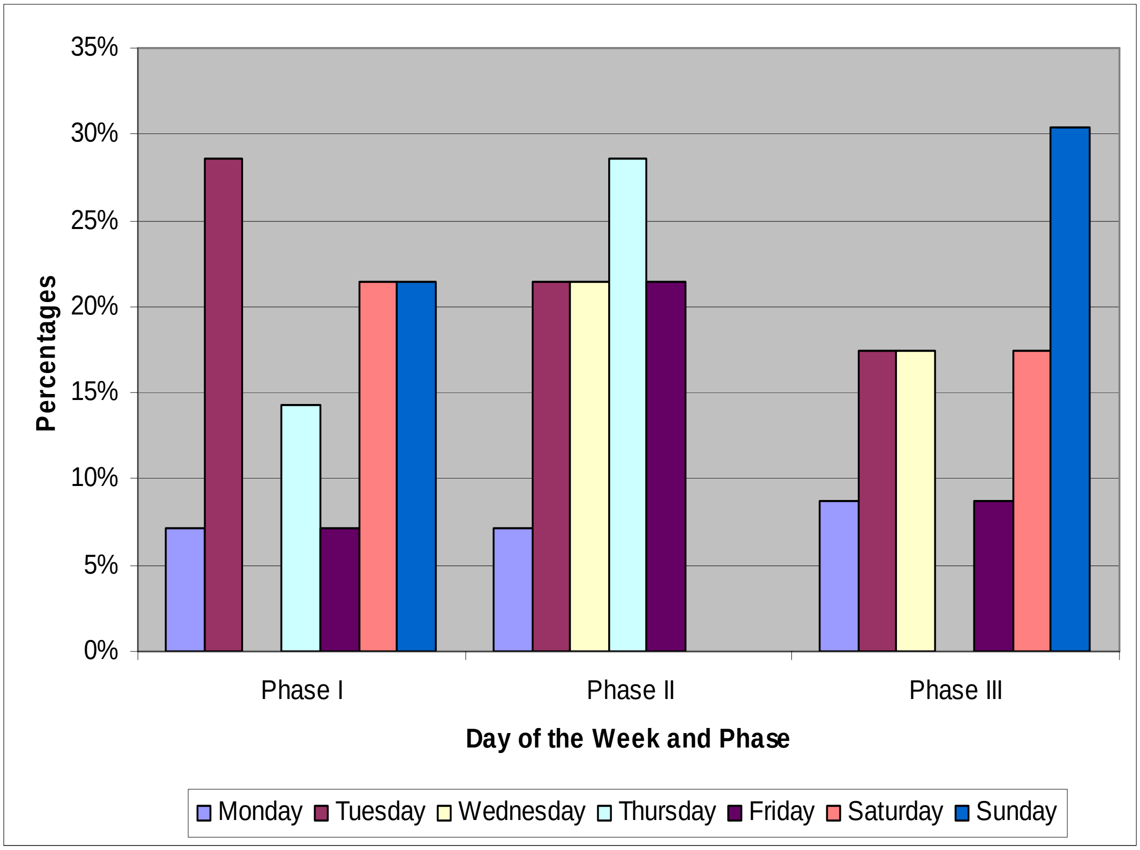

Figure C-49 Distribution of Crashes by Day of the Week and Phase (I-15 Study Site)

Figure C-50 shows distribution of crash rates by light condition and construction phase. In all three phases, most crashes took place in 'dark street or highway not lighted' and 'daylight' conditions. In Phase I, some crashes also took place in the 'dark street or highway lighted' condition.

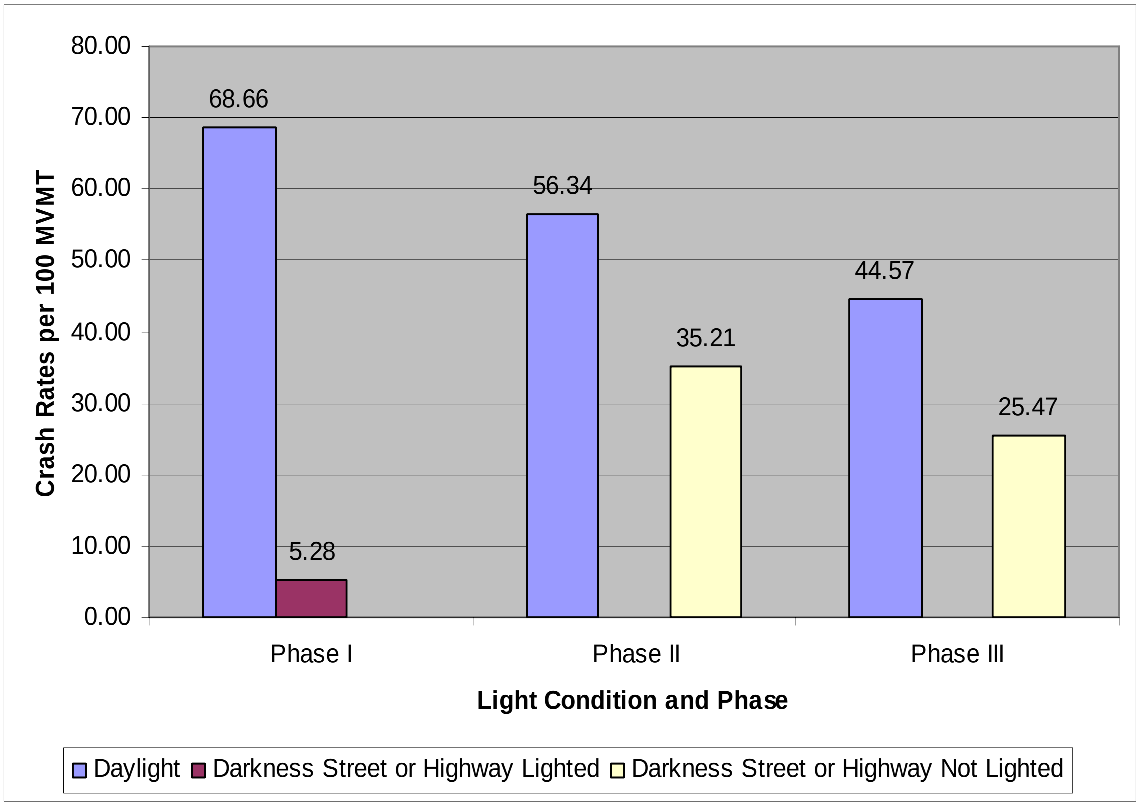

Figure C-50 Distribution of Crash Rates by Light Condition and Phase (I-15 Study Site)

Figure C-51 shows the distribution of crash rates by traffic control method and construction phase. In all the phases, most crashes took place at locations which were recorded as 'construction or work areas' and 'traffic lanes were marked', which means that they took place in the travel lanes. In Phase II and Phase III, the highest crashes were in the 'construction or work area', while the highest crashes in Phase III were in 'traffic lanes were marked' zone. Many traffic control methods in Phase III were more related to crashes than those in Phase I and Phase II.

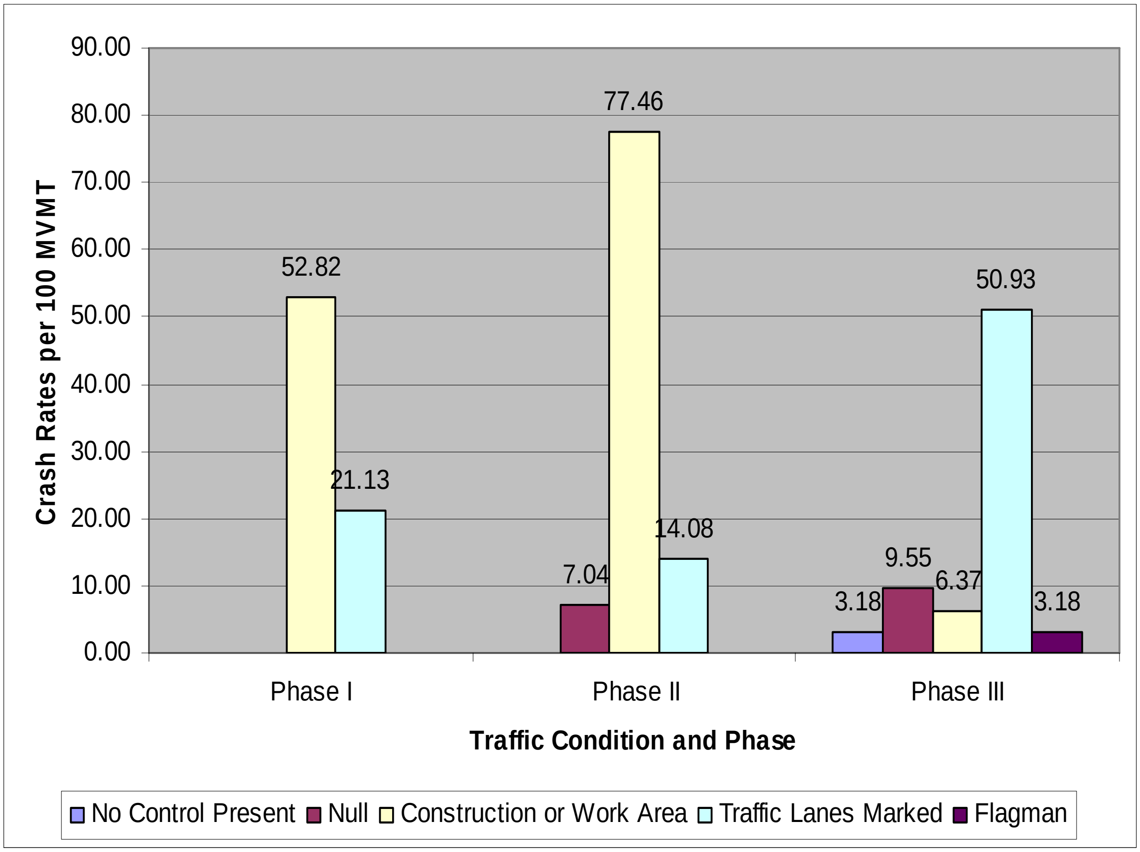

Figure C-51 Distribution of Crash Rates by Traffic Control Method and Phase (I-15 Study Site)

Figure C-52 shows the distribution of crash rates by alignment and construction phase. The trends of all the phases were different from each other. In all the phases, some crashes in the 'grade straight' and 'straight and level' sections were higher than those in the other sections. The highest crash rate was in the 'grade straight' section for Phase I, in the 'straight and level' section for Phase II, and in the 'grade straight' and 'straight and level' sections for Phase III. In Phase I and Phase III, some crashes took place in the 'curve grade' section.

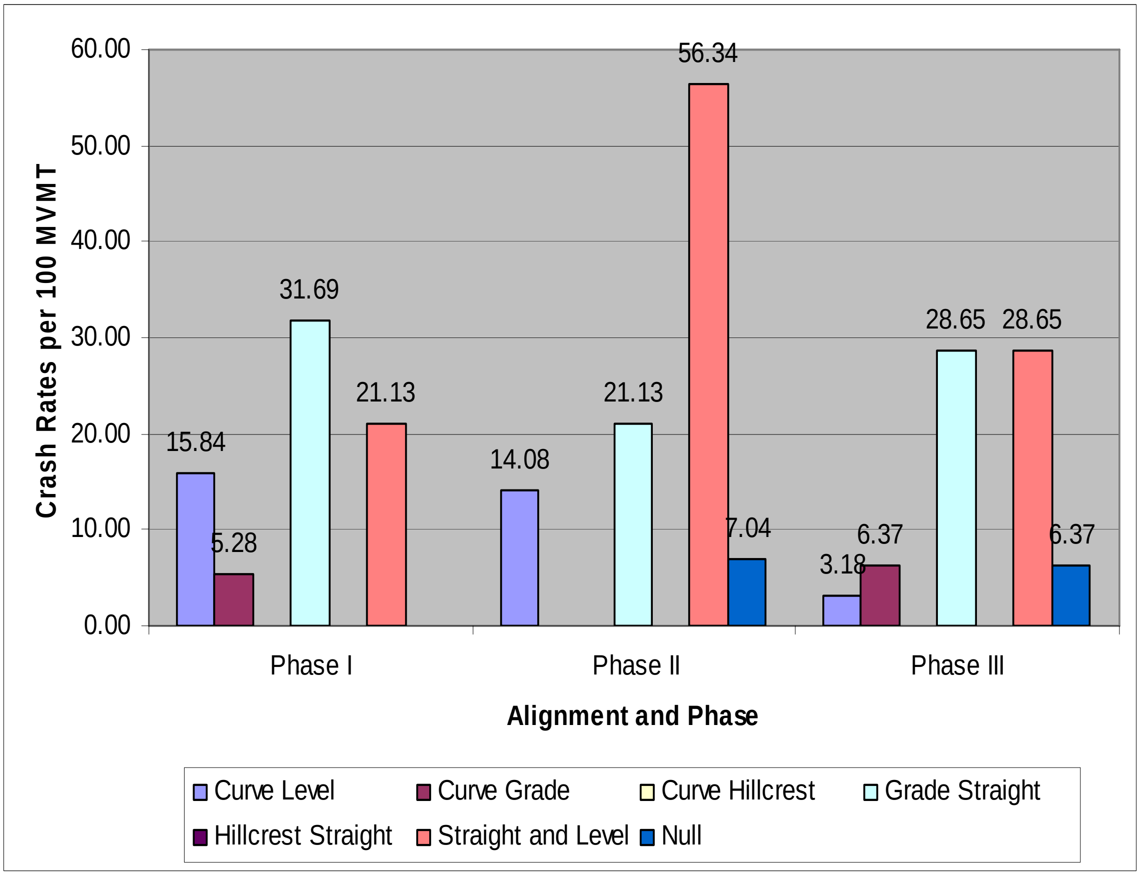

Figure C-52 Crash Rates by Alignment and Construction Phase (I-15 Study Site)

Figure C-53 shows the distribution of crash rates by weather condition and construction phase for the work zone. Most crashes took place in the ‘clear’ or ‘cloudy’ weather conditions. The crash rate for the ‘snowing’ condition was the highest in Phase III among the three phases. This is understandable because Phase III had a winter season. The crash rate for the ‘clear’ condition was the highest in Phase II. Phase I experienced crashes in the ‘fog’ or ‘raining’ condition, which the other phases did not experience.

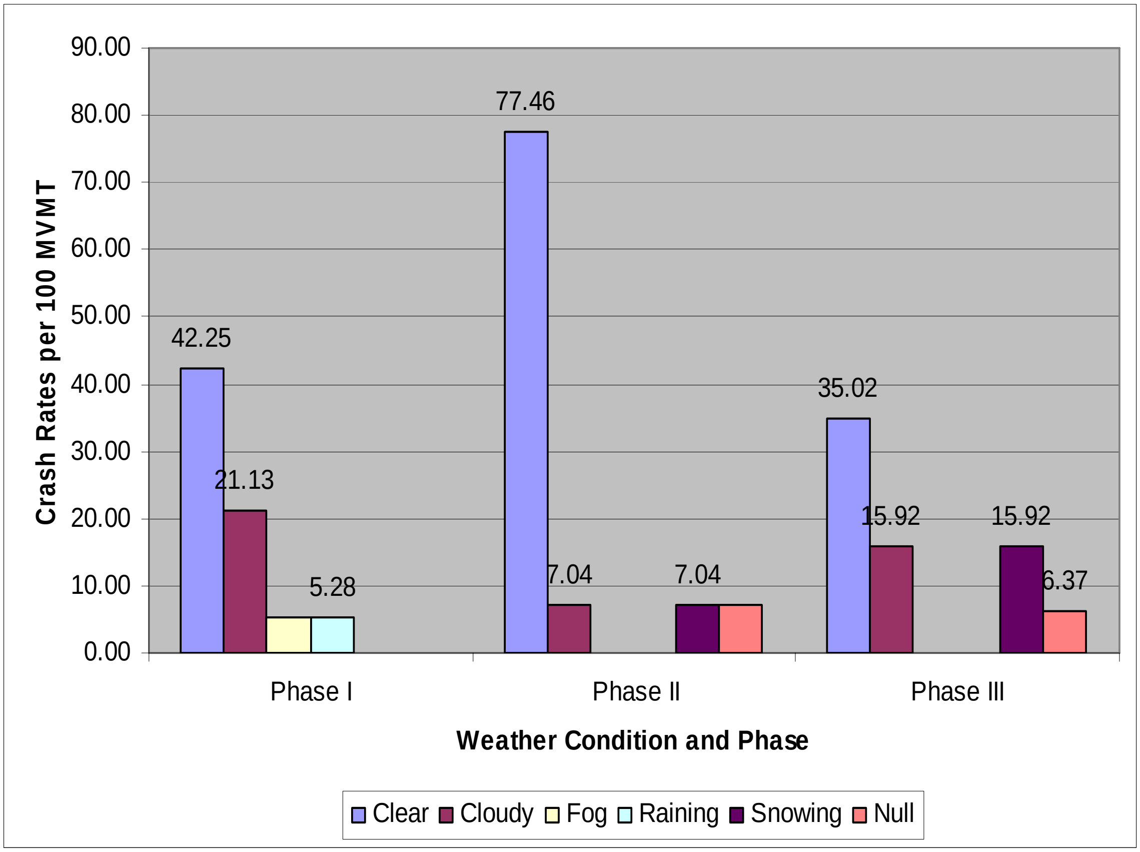

Figure C-53 Distribution of Crash Rates by Weather Condition and Construction Phase (I-15 Study Site)

Figure C-54 shows the distribution of crash rates by surface condition and construction phase. Crash rates in the 'dry' condition were the highest in all three phases. All four types of surface condition related crashes took place in each phase. It is interesting to note that crash rates of the other surface conditions, 'snowy' and 'wet' conditions, were similar in all three phases except in Phase III where the crash rate for the 'snowy' condition was twice as high as the 'wet' condition.

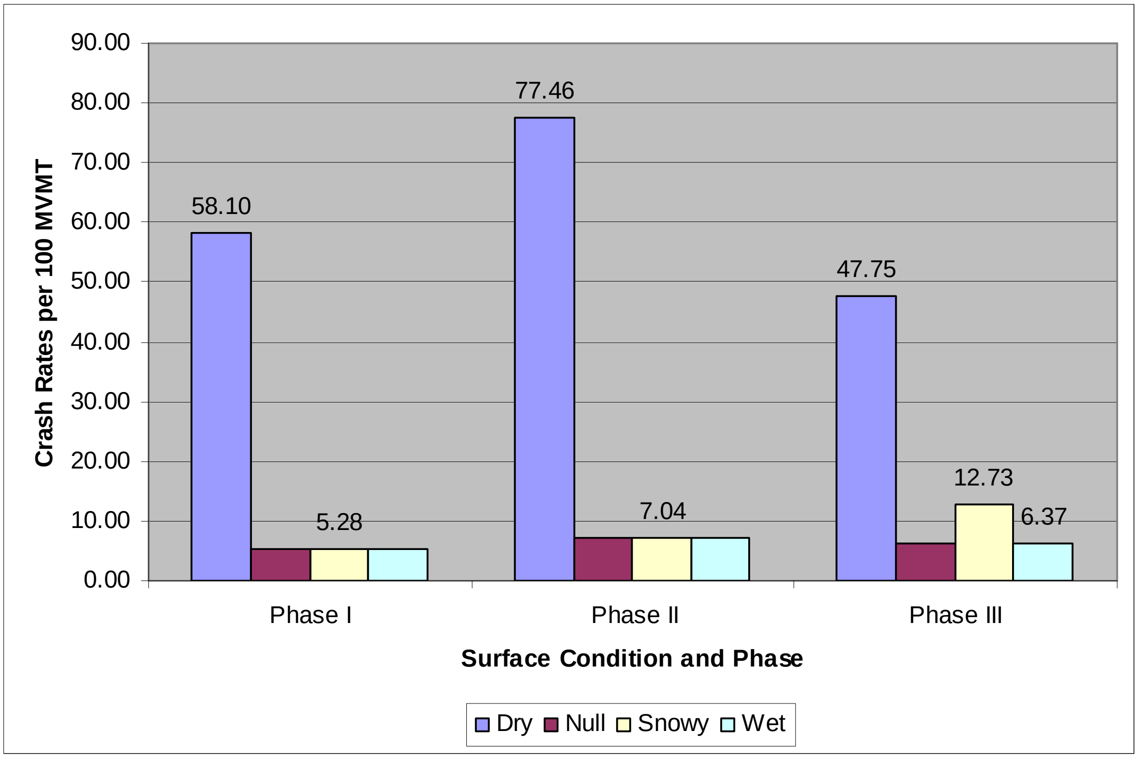

Figure C-54 Distribution of Crash Rates by Surface Condition and Construction Phase (I-15 Study Site)

Table C-33 shows crash rates by involvement and construction phase. The majority of crashes involved 'single vehicle' crashes in Phases II and III. In Phase I, crash rates for 'single' and 'multiple vehicles' crashes were the same.

Table C-33 Crash Rates by Involvement and Phase (I-15 Study Site)

(Unit: Crashes per 100MVMT)

	Phase I	Phase II	Phase III
MV-MV	36.97	35.21	15.92
Single vehicle	36.97	63.38	57.30
Total	73.94	98.59	73.22

Table C-34 shows crash type breakdown by construction phase. The highest number of crashes in Phase I and Phase II involved 'multi-vehicles'. On the other hand, the 'ran-off roadway-right' crash type had the highest number of occurrences in Phase III. Phase III also had the ‘ran-off roadway-left’ and ‘MV-MV’ broken crash types.

Table C-34 Crash Type Breakdown by Construction Phase (I-15)

(Unit: Number of crashes)

# of Vehicle	Crash Type	Phase I	Phase II	Phase III
Single Vehicle	MV-Animal(Wild)	0	0	2
	MV-Fixed Object	1	3	1
	MV-Other Object	2	1	0
	Ran Off Roadway-Left	1	1	5
	Ran Off Roadway-Right	2	2	8
	Ran Off Roadway-Thru Median	0	1	2
	Other Non-Collision	0	1	0
	Overturned	1	0	0
MV-MV	MV-MV	6	5	5
	MV-MV(Other objects)	1	0	0
Total		14	14	23

C.2.4 Seasonal Analysis

C.2.4.1 General Outline

To analyze the crash distribution in the summer season during construction, crashes that happened in June, July, August of 2002 and June of 2003 were analyzed. Table C-35 shows a summary of crashes that took place in the summer months. Even though the number of these summer months was four, the number of crashes and annual number average crashes during these summer months were higher than the average values over the entire construction period. Compared with Table C-25, crash rates per 100 MVMT for the summer months were 200.35 before construction, 159.77 during construction, and 61.64 after construction. These results were much higher than the total crash rates, 80.00 before construction, 79.01 during construction, and 40.72 after construction.

Table C-35 Number of Crashes in Summer Months (I-15 Study Site)

Construction Time	Total Crashes (# of crashes)			Annual Average Number of Crashes (crashes/year)		
	Before	During	After	Before	During	After
04/00/2002 – 06/30/2003	115	51	32	38.33	79.01	40.72
Summer Season (June, July, August)	**24**	**22**	**9**	**96.0**	**82.50**	**32.4**

Figure C-55 shows total crash rates for summer-months and total crash rates during construction by severity. 'No injury' crashes had the highest frequency in all construction phases in both summer and throughout the construction period. Both the summer months and the entire construction period had similar trends in crash occurrences. Overall, crash rates decreased after construction. After construction, severe crashes in the summer months such as 'broken bones or bleeding bleed' or 'fatal' crashes disappeared.

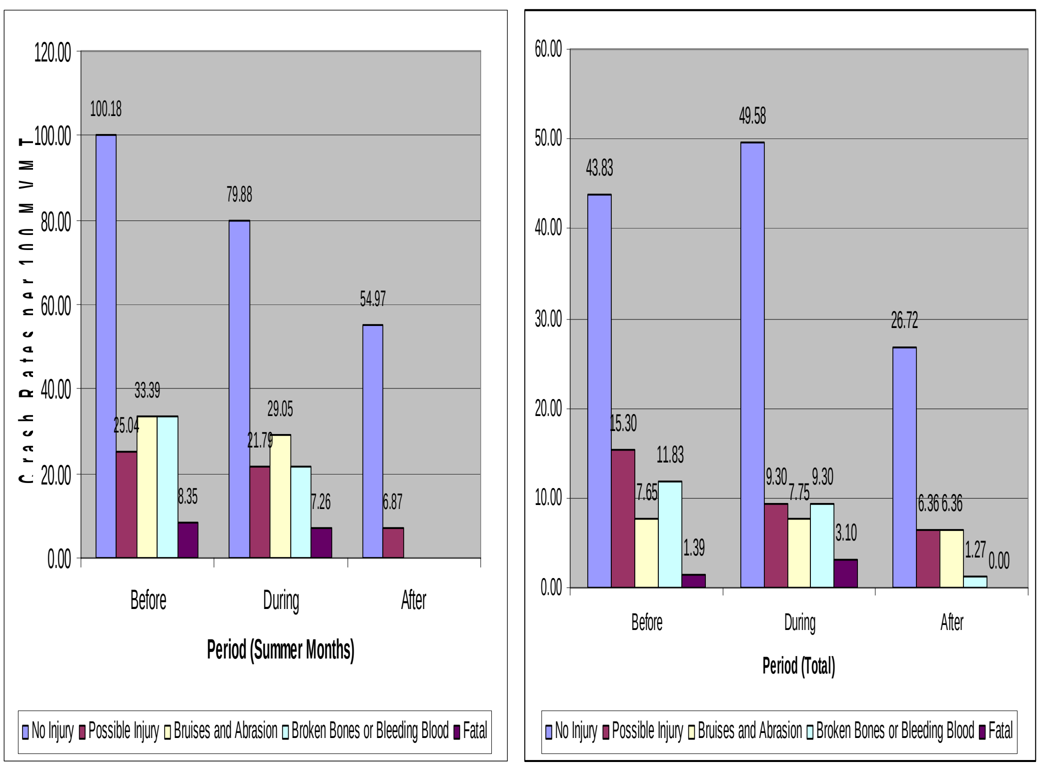

Figure 4-55 Summer-Month and Total Crash Rates during Construction by Severity (I-15 Study Site)

C.2.4.2 Spatial and Temporal Crash Analysis

Figure C-56 compares the spatial and temporal crash rates for the summer months by milepost in the work zone. Overall, crash occurrences in the summer months were similar to those of the entire construction period by milepost.

The location with the highest crash rate was a mile section between MP 205.01- MP 206.00 before construction, MP 208.01 – MP 209.00 during construction, and MP 200.07 – MP 201.00 after construction, which was similar to the crash occurrence trend over the entire construction period. However, crash rates were quite different at some locations in the summer months compared to the trend for the entire construction period. Nevertheless, overall crash rates are much smaller in the after construction period than in the before or during construction periods.

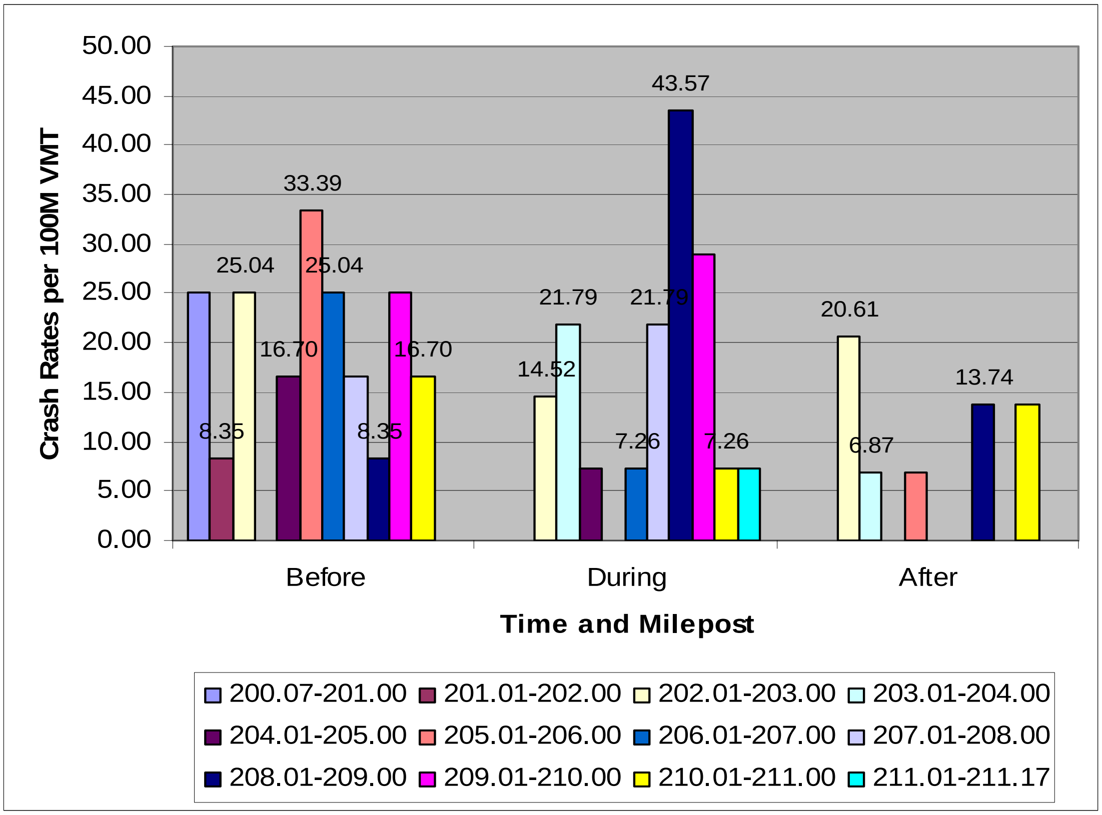

Figure C-56 Spatial & Temporal Crash Rate Comparison for Summer Months by Milepost in Work Zone (I-15 Study Site)

Figure C-57 shows crash distribution in percentages by day of the week for the summer months. The crash distribution trends for the summer months were different from the trends observed for the entire construction duration.

The highest crash rate happened on Wednesday before construction, on Wednesday, Friday, and Sunday during construction, and on Monday after construction. Crashes for before and after construction took place in the early part of the week, while crashes during construction spread over the week evenly. There were no crashes on Sunday after construction in the summer months, which was the same trend observed in the crash occurrence trend for the entire construction period.

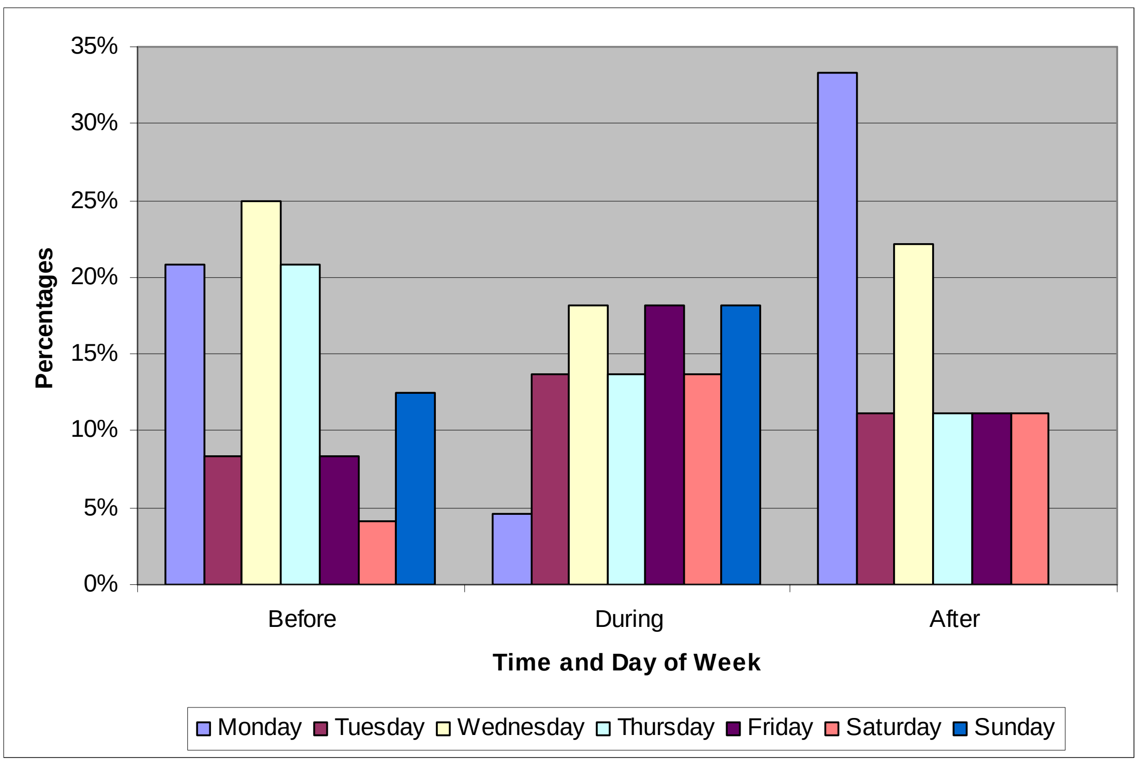

Figure C-57 Crash Occurrences in Summer Months by Day of the Week (I-15 Study Site)

Figure C-58 shows the distribution of hourly crash rates during construction by the time of the day in the summer months. Total number of crashes for this work zone was 22 for the entire construction period. Hours that had two crashes were the AM peak period (7:00-8:00 AM), around noon (11:00-12:00AM, 1:00-

2:00 PM) and in the PM peak period (4:00-5:00, 6:00-8:00 PM). No crashes were recorded in a few hour slots.

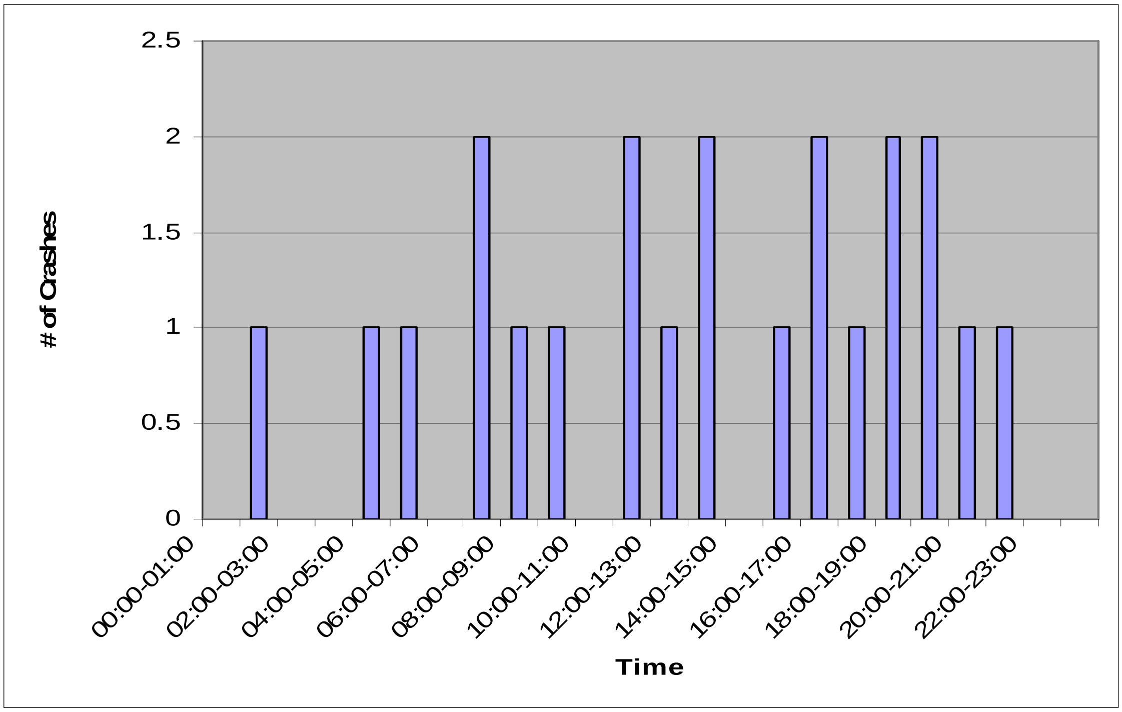

Figure C-58 Distribution of Hourly Crash Rate during Construction by Time of the Day in the Summer Months (I-15 Study Site)

C.2.4.3 Other Analyses

Figure C-59 shows seasonal crash rates in the summer months by light condition. Most crashes took place in the ‘daylight’ or ‘dark street or highway not lighted’ light conditions. More crashes happened in the ‘dark street or highway not lighted’ condition before construction than during and after construction. Less number of crashes happened in the ‘dark street or highway not lighted’, ‘dusk’, and ‘dawn’ conditions before and during construction. These trends in the summer months for light condition are similar to the trends observed for the entire duration of construction as seen in Figure C-35.

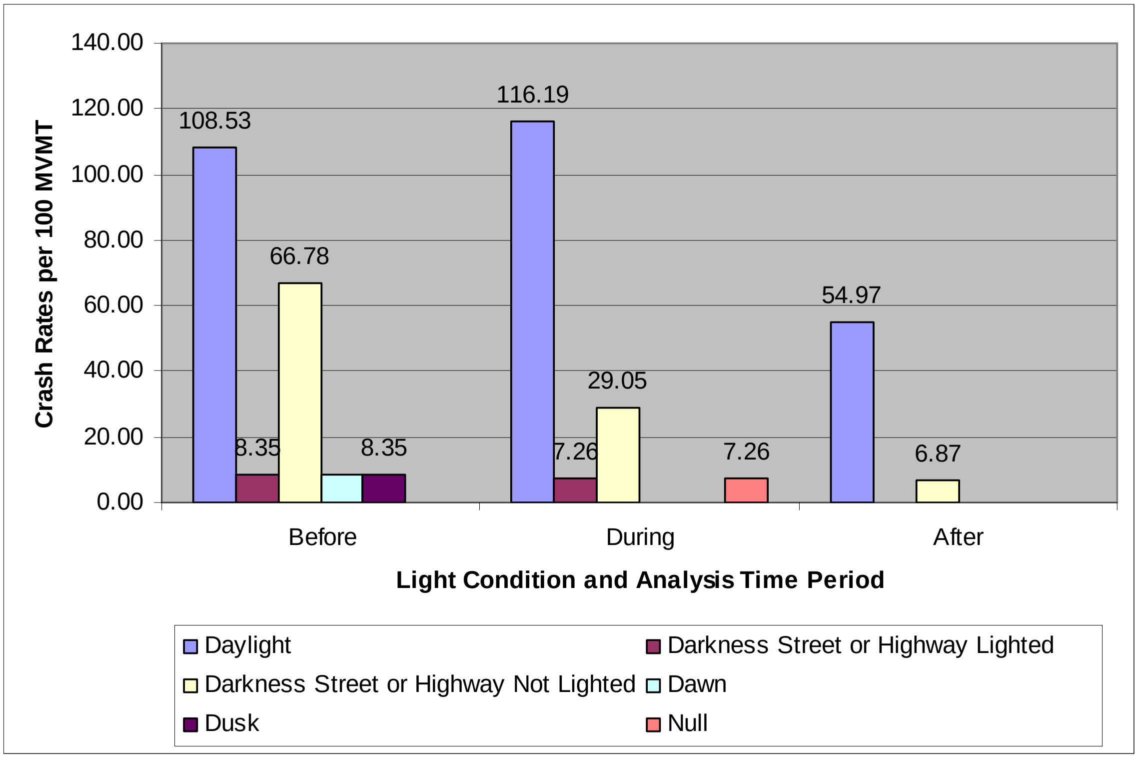

Figure C-59 Crash Rates in Summer Months by Light Condition (I-15 Study Site)

Figure C-60 shows crash rates in the summer months by analysis period and traffic control, or where crashes took place. Crash rates were the highest in the 'traffic lanes marked' condition before and after construction. On the other hand, the highest crash rate during construction was recorded in the 'construction or work area' condition.

Other traffic controls had much less crash rates in the three periods. These trends are similar to those found for the entire duration of construction as seen in Figure C-36.

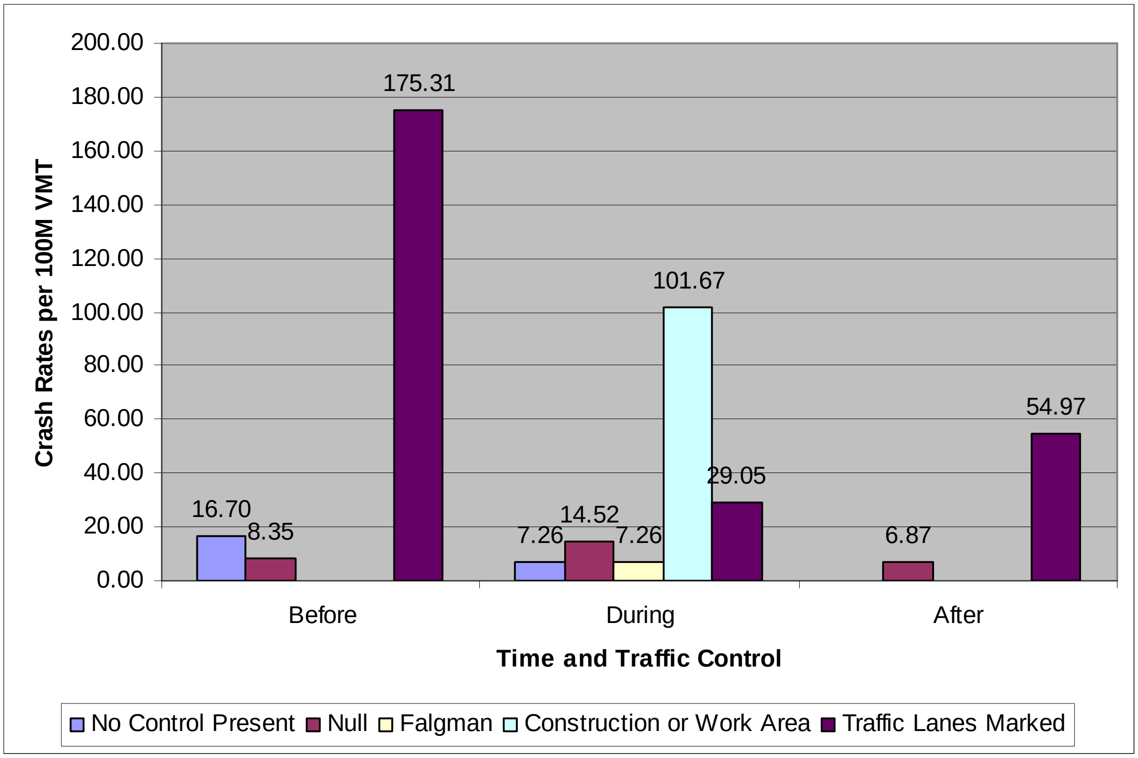

Figure C-60 Crash Rates in Summer Months by Analysis Period and Traffic Control (I-15 Study Site)

Figure C-61 presents crash rates in the summer months by alignment for each period. The highest crash rate by alignment was different for each period: the ‘straight and level’ section before and after construction and the ‘grade straight’ section during construction. Most crashes happened in the ‘straight and level’ and ‘grade straight’ sections. ‘Curve grade’ and ‘curve level’ sections had some crashes before and during construction. Crashes in all sections decreased or disappeared after construction. These trends are all similar to those for the entire construction period as seen in Figure C-37.

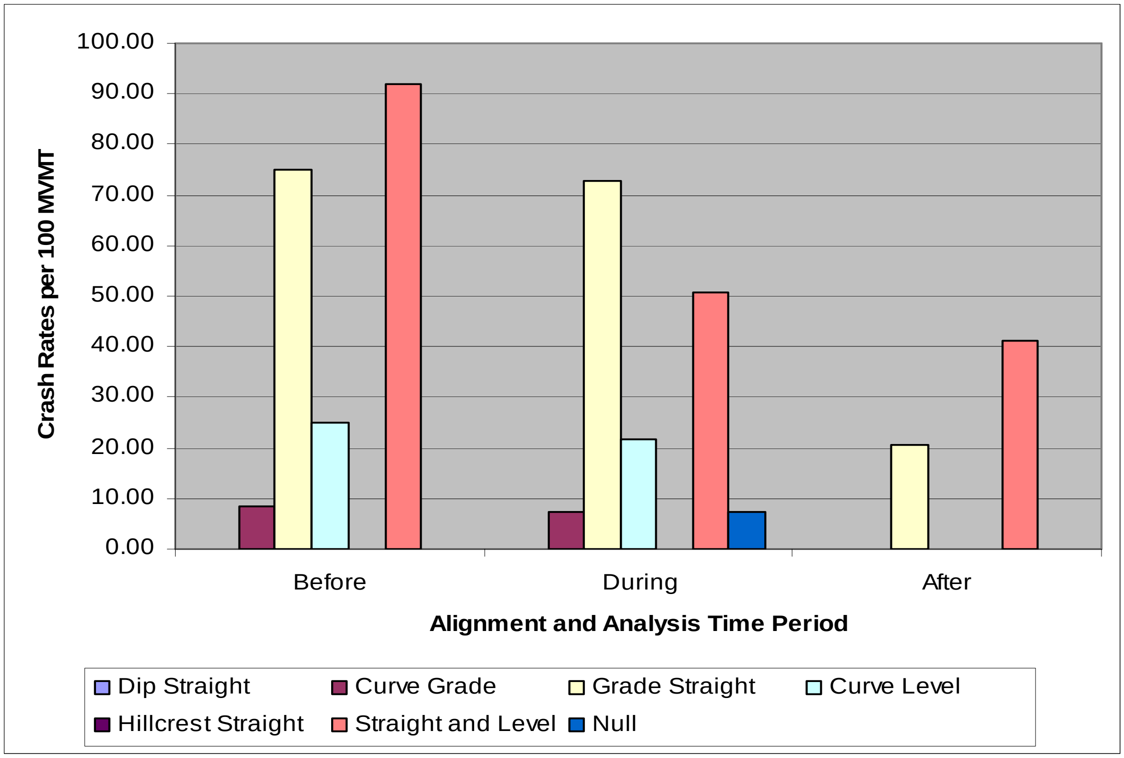

Figure C-61 Crash Rates in Summer Months by Analysis Period and Alignment (I-15 Study Site)

Figure C-62 presents crash rates in the summer months by weather condition. Most crashes happened in the 'clear' weather condition. A much less number of crashes happened in the 'cloudy' condition. These trends are somewhat different from those for the entire construction period by weather condition as seen in Figure C-38. All crashes took place on the 'dry' surface condition for each period.

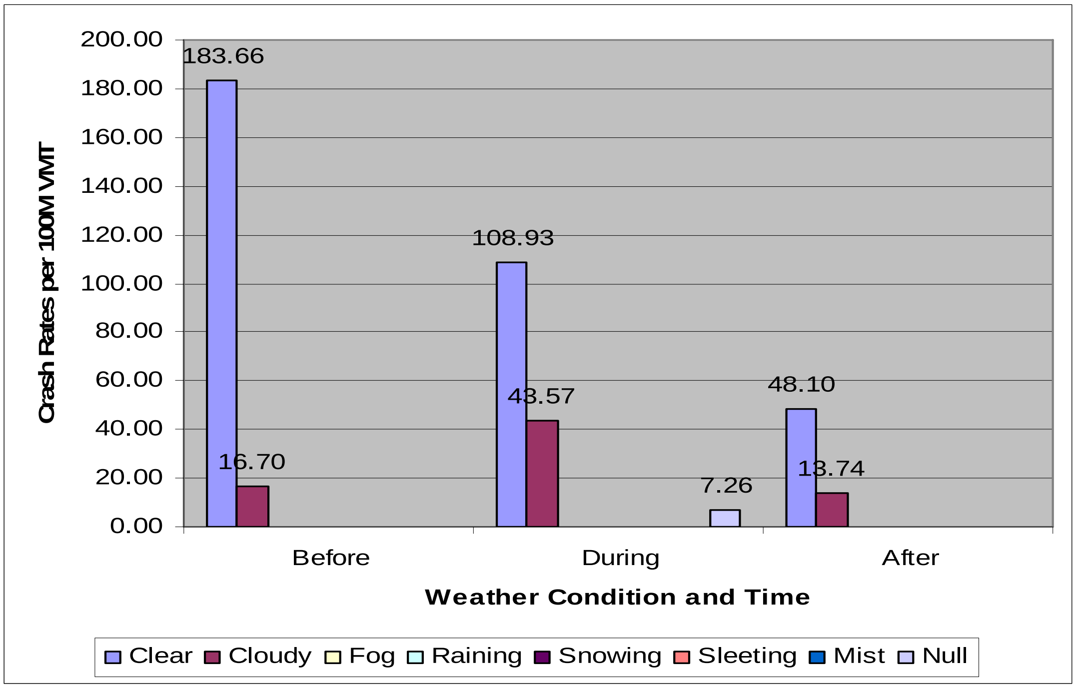

Figure C-62 Crash Rates in Summer Month by Analysis Period and Weather Condition (I-15 Study Site)

Table C-36 shows crash rates by vehicle involvement. In the after construction period, all crashes were involved in 'single vehicle' crashes. Some crashes in the before and during construction periods involved 'MV-MV' crashes. These trends are similar to those of the entire crash rates by vehicle involvement, as seen Table C-26

Table C-36 Seasonal Crash Rates by Analysis Period and Vehicle Involvement (I-15 Study Site)

	Before	During	After
MV-MV	8.35	50.83	0.00
Single vehicle	192.01	108.93	61.84
Total	200.35	159.77	61.84

Table C-37 shows the number of crashes in the summer months by crash type during construction in the work zone. Twenty-seven percent of the crashes in the summer months were related to the ‘MV-MV’ crash type, and thirty-two percent of crashes were related to the ‘run-off roadway–right’ crash type. Other crashes were related to the ‘MV-animal (domestic)’, ‘MV-fixed object’, ‘MV-other object’, ‘ran off roadway-left’, ‘other non-collision’ and ‘overturned’ crash types. These findings are similar to those found for the crashes for the entire duration of construction as seen in Table C-27.

Table C-37 Number of Crashes in Summer Months by Crash Type during Construction (I-15 Study Site)

Number of Vehicle	Accident Type	#of Crashes
Single Vehicle	MV-Animal(Domestic)	1
	MV-Animal(Wild)	0
	MV-Fixed Object	1
	MV-Other Object	3
	Ran Off Roadway-Left	2
	Ran Off Roadway-Right	7
	Ran Off Roadway-Thru Median	0
	Other Non-Collision	1
	Overturned	1
MV-MV	MV-MV	6
	MV-MV(Other Objects)	0
Total		22

C.2.5 Summary and Conclusion

C.2.5.1 General Analysis

Table C-38 summarizes the results of spatial and temporal analyses of the work zone on I-15. This rehabilitation and reconstruction project was 11.0 mile long and lasted for 15 months. The traffic control cost was 6.7 percent of the total construction cost. In the case of crash analysis by severity, even though ‘broken bones or bleeding blood’ crashes dominated the three analysis periods, ‘fatal’ crashes had the highest crash rate during the construction period.

The spatial and temporal crash analysis revealed that the upstream and downstream sections of the work zone were more dangerous than the actual work zone at this site. Sections with the highest ‘broken bones and bleeding blood’ and ‘fatal’ crashes were two or three miles south or north of the work zone for the three analysis periods. The section with the highest change in the ‘broken bones or bleeding blood’ crash rate was a one-mile section south of the work zone, from MP 199.07 to MP 200.06, and the section with the highest change in the ‘fatal’ crash rate was a one-mile section south of the work zone, from MP 198.07 to MP 199.06 (i.e., The 2nd mile section south of the work zone).

The spatial and temporal crash rates comparison by milepost in the work zone showed that the section with the highest changes in crash rates as time proceeded from before construction to after construction, were from MP 206.01 to MP 207.00 before construction, from MP 208.01 to MP 209.00 during construction, and from MP 200.07 to MP 201.00 after construction. Within the work zone (from MP 200.07 to MP 211.17), the mid-sections (from MP 206.0 to MP 208.0) were the most dangerous overall, while the south end of the work zone (from MP 200.07 to MP 201.0) was found to be the most dangerous after construction. The one mile section with the highest increase in crash rates was recorded between MP 200.07 and MP 201.00.

The monthly crash rate distribution analysis showed that June of 2003 had the highest crash rate with 58.10 crashes per 100 MVMT, and the months with the lowest crash rates were April of 2002 and April of 2003 with 7.26 crashes per 100 MVMT.

Table C-38 Summary of Spatial and Temporal Analysis Results (I-15 Study Site)

Main Factor	Contents	
General Outline		
Construction Duration	April 2002 - June 2003	15 months
Span of Work Zone	MP 200.07 - 211.17	11.0 miles
Main Works	Rehabilitation & Reconstruction	
Traffic Control Cost	$1,330,000	6.7% of Total Construction Cost ($19.85 million)
Crash Analysis by Severity (Crashes per 100 MVMT)		
Before (Apr. 1999 - Mar. 2002)	Broken Bones or Bleeding Blood (BBBB)	11.83
	Fatal	1.39
During (Apr. 2002 - Jun. 2003)	Broken Bones or Bleeding Blood	9.30
	Fatal	3.10
After (Jul. 2003 - Dec. 2004)	Broken Bones or Bleeding Blood	1.27
	Fatal	0.00
Spatial and Temporal Crash Analysis (Crashes per 100 MVMT)		
Before	Section with the Highest BBBB Crash Rates	North 3 mile (MP 213.08-214.17, 31.57)
	Section with the Highest Fatal Crash Rates	North 2 mile (MP 212.18-213.17, 7.89) North 3 mile (MP 213.18-214.17, 7.89)
During	Section with the Highest BBBB Crash Rates	South 2 mile (MP 198.07-199.06, 34.36) South 3 mile (MP 199.07-200.06, 34.36)
	Section with the Highest Fatal Crash Rates	North 2 mile (MP 212.18-213.17, 34.56)
After	Section with the Highest BBBB Crash Rates	North 2 mile (MP 212.18-213.17, 42.87)
	Section with the Highest Fatal Crash Rates	South 1 mile (MP 199.07-200.06, 14.01) South 2 mile (MP 198.07-199.06, 14.01) South 4 mile (MP 196.07-197.06, 14.01)
Section with the Highest Increasing BBBB Crash Rates From Before to After		North 2 mile (MP 212.18-213.17, 7.89→42.97)
Section with the Highest Decreasing BBBB Crash Rates From Before to After		North 3 mile (MP 213.18-214.17, 31.57→14.29)
Section with the Highest Increasing Fatal Crash Rates From Before to After		South 1 mile (MP 199.07-200.06, 0.00→14.01) South 2 mile (MP 198.07-199.06, 0.00→14.01) South 4 mile (MP 196.07-197.06, 0.00→14.01)
Section with the Highest Decreasing Fatal Crash Rates From Before to After		North 2 mile (MP 212.18-213.17, 7.89→0.00) North 3 mile (MP 213.18-214.17, 7.89→0.00)
Section with the Highest BBBB Crash Rate Changes From Before To During Construction		South 1 mile (MP 199.07-200.06, 0.00→34.36)
Section with the Highest Fatal Crash Rate Changes From Before To During Construction		South 2 mile (MP 198.07-199.06, 0.00→17.18)
Spatial and Temporal Crash Rate Comparison by Milepost in Work Zone (Crashes per 100 MVMT)		
Before	Section with the Highest Crash Rates	MP 206.01-207.00 (11.83)
	Section with the Lowest Crash Rates	MP 204.01-205.00, MP 211.01-211.17 (0.00)
During	Section with the Highest Crash Rates	MP 208.01-209.00 (18.59)
	Section with the Lowest Crash Rates	MP201.01-202.00, MP 205.01-206.00 (0.00)
After	Section with the Highest Crash Rates	MP 200.07-201.00 (7.63)
	Section with the Lowest Crash Rates	MP 211.01-211.17 (0.00)
Section with the Largest Increase in Crash Rates From Before To After		MP 200.07-201.00 (4.17→7.63)
Section with the Largest Decrease in Crash Rates From Before To After		MP 207.01-208.00(11.13→1.27)
Monthly Crash Rate Distribution Analysis During Construction (Crashes per 100 MVMT)		
Month with the Highest Crash Rates		Jun 2003 (58.10)
Month with the Lowest Crash Rates		Apr. 2002, Apr. 2003 (7.26)

Table C-39 summarizes the results of analysis between crash rate and other factors such as light condition, traffic control method, alignment, weather condition and surface condition. Crash rate analysis by severity and light condition during construction showed that 'broken bones or bleeding' and 'fatal' crashes mostly took place in the 'daylight' and 'dark street or highway not lighted' conditions. The majority of crashes took place in the 'daylight' condition with 72.5 percent, followed by the 'dark street or highway lighted' condition with 25.2 percent.

The crash rate analysis by analysis period and traffic control showed that most of the crashes took place in the 'traffic lanes marked' sections before construction. During construction, the highest crash rate happened in the 'construction or work area' sections. After construction, the 'traffic lane marked' sections again had the highest crash rate.

The crash rate analysis by analysis period and alignment showed that the 'straight and level' section had the highest crash rate, while the 'dip straight' and 'hillcrest straight' sections had the lowest crash rates. The alignment with the largest decrease in crash rate from before to after construction was the 'grade straight' section.

The crash rate analysis by analysis period and weather condition showed that the highest crash rates happened in the 'clear' weather condition during the three construction periods, while lower crash rates happened in the other weather conditions including the 'fog' condition. After construction, the weather condition with the largest decrease in crash rate was the 'clear' weather condition.

The crash rate analysis by analysis period and surface condition showed that the highest crash rates took place in the 'dry' surface condition, while the lowest crash rates took place in the 'muddy' condition. After construction, the surface condition with the largest decrease in crash rate was the 'clear' condition.

The analysis of the number of crash rates by crash type during construction showed that among the crash types analyzed, crashes involving 'MV-MV' had the highest number of crashes, 22 crashes out of a total of 51 crashes.

Table C-39 Summary of Other Analysis Results (I-15 Study Site)

Main Factor		Contents
Crash Rate Analysis by Severity and Light Condition during Construction (Crashes per 100 MVMT)		
Broken Bones or Bleeding Blood		Daylight (7.75), Dark Street or Highway Not Lighted (1.55)
Fatal		Daylight (1.55), Dark Street or Highway Not Lighted (1.55)
Percentage Share of Light Condition for Crashes		Daylight (72.5%)
		Dark Street or Highway Not Lighted (25.5%)
		Dark Street or Highway Lighted (2.00%)
Crash Rate Analysis by Analysis Period and Traffic Control (Crashes per 100 MVMT)		
Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (73.74)
	Traffic Control with the Lowest Crash Rates	No Passing Lanes, Flagman, Construction or Work Area (0.00)
During	Traffic Control with the Highest Crash Rates	Construction or Work Area (35.63)
	Traffic Control with the Lowest Crash Rates	No Passing Lanes (0.00)
After	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (35.63)
	Traffic Control with the Lowest Crash Rates	No Control Present, Flagman, Construction or Work Area, No Passing Lanes (0.00)
Traffic Control with the Largest Increase in Crash Rates From Before To After		Traffic Signal (0.70→1.27)
Traffic Control with the Largest Decrease in Crash Rates From Before To After		Traffic Lane Marked (73.74→35.63)
Crash Rate Analysis by Analysis Period and Alignment (Crashes per 100 MVMT)		
Before	Alignment with the Highest Crash Rates	Straight and Level (39.65)
	Alignment with the Lowest Crash Rates	Dip Straight (0.00)
During	Alignment with the Highest Crash Rates	Straight and Level (32.53)
	Alignment with the Lowest Crash Rates	Dip Straight, Hillcrest Straight (0)
After	Alignment with the Highest Crash Rates	Straight and Level (24.18)
	Alignment with the Lowest Crash Rates	Hillcrest Straight (9.29)
Alignment with the Largest Increase in Crash Rates From Before To After		Dip Straight (0.00→2.54)
Alignment with the Largest Decrease in Crash Rates From Before To After		Grade Straight (30.61→8.91)
Crashes Rate Analysis by Analysis Period and Weather Condition (Crashes per 100 MVMT)		
Before	Weather Condition with the Highest Crash Rates	Clear (48.0)
	Weather Condition with the Lowest Crash Rates	Fog (0.00)
During	Weather Condition with the Highest Crash Rates	Clear (46.48)
	Weather Condition with the Lowest Crash Rates	Fog, Mist (0.00)
After	Weather Condition with the Highest Crash Rates	Clear (25.45)
	Weather Condition with the Lowest Crash Rates	Fog, Raining, Mist (0.00)
Weather Condition with the Largest Increase in Crash Rates From Before To After		-
Weather Condition with the Largest Decrease in Crash Rates From Before To After		Clear (48.00→25.45)
Crashes Rate Analysis by Analysis Period and Surface Condition (Crashes per 100 MVMT)		
Before	Surface Condition with the Highest Crash Rates	Dry (54.26)
	Surface Condition with the Lowest Crash Rates	Muddy (0.70)
During	Surface Condition with the Highest Crash Rates	Dry (57.32)
	Surface Condition with the Lowest Crash Rates	Icy, Muddy (0.00)
After	Surface Condition with the Highest Crash Rates	Dry (35.63)
	Surface Condition with the Lowest Crash Rates	Muddy (0.00)
Surface Condition with the Largest Increase in crash rates From Before To After		-
Surface Condition with the Largest Decrease in Crash Rates From Before To After		Dry (54.26→35.63)
Number of Crashes by Crash Types during Construction (Number of Crashes Involved Crash Type/ Total Number of Crashes)		
The Highest Crash Type		MV-MV (22/51)

C.2.5.2 Directional Analysis

Table C-40 summarizes the results of spatial and temporal analyses by direction on I-15. Crash rate analysis by direction showed that the crash rates of the northbound direction were similar to those of the southbound direction.

The spatial and temporal crash rate comparison by direction and milepost in the work zone revealed that the one mile sections with the highest crash rates for the northbound and southbound directions were quite different in the during and after periods. The one mile section with the largest decrease in crash rates from the before to after periods was from MP 207.01 to MP 208.00 for both directions, while the one mile section with the largest increase in crash rates from the before to after construction periods was from MP 200.07 to MP 201.00 for the northbound direction and from MP 203.01 to MP 204.00 for the southbound direction.

The crash analysis by severity and direction showed that crashes which happened on the southbound direction were more severe than those on the northbound direction in the before and during periods. In the after period, 'broken bones or bleeding blood' crashes took place in the northbound direction; however, 'broken blood or bleeding blood' crashes didn't happen in the southbound direction. Also, 'fatal' crashes didn't happen in either direction in the after period.

Monthly crash rate distribution by direction during construction showed that the months with the highest crash rates in the northbound and the southbound directions were June of 2003 and June of 2002, respectively. However, the months with the lowest crash rates in the northbound and southbound directions were quite different.

Table C-40 Summary of Spatial and Temporal Analysis Results by Direction (I-15 Study Site)

Main Factor	Contents		Direction	
			Northbound	Southbound
Crash Rates Analysis (Crashes per 100 MVMT)				
	Before		39.86	41.04
	During		37.18	38.73
	After		20.36	20.36
Spatial and Temporal Crash Rate Comparison by Direction Milepost in Work Zone (Crashes per 100 MVMT)				
	Before	Section with the Highest Crash Rates	MP 206.01-207.00 (5.57)	MP 206.01-207.00 MP 207.01-208.00 (6.26)
		Section with the Lowest Crash Rates	MP 204.01-205.00 (0.70)	MP 203.01-204.00, MP 211.01-211.17 (0.70)
	During	Section with the Highest Crash Rates	MP 201.01-202.00 MP 202.01-203.00 (6.20)	MP 207.01-208.00 MP 208.01-209.00 (7.75)
		Section with the Lowest Crash Rates	MP 201.01-202.00 (0.00)	MP 201.01-202.00 (0.00)
	After	Section with the Highest Crash Rates	MP 208.01-209.00 (3.82)	MP 202.01-203.00 MP 203.01-204.00 MP 210.01-211.00 (3.82)
		Section with the Lowest Crash Rates	MP 210.01-211.00, MP 211.01-211.17 (0.00)	MP 205.01-209.00 MP 211.01-211.17 (0.00)
	Section with the Largest Increase in Crash Rates From Before To After		MP 200.07-201.00 (2.78→ 3.82)	MP 203.01-204.00 (0.70→ 3.82)
	Section with the Largest Decrease in Crash Rates From Before To After		MP 207.01-208.00 (4.87→ 1.27)	MP 206.01-207.00, MP 207.01-208.00 (6.26→ 0.00)
Crash Analysis by Severity and Direction (Crashes per 100 MVMT)				
	Before	Broken Bones or Bleeding Blood (BBBB)	4.87	6.96
		Fatal	0.70	0.70
	During	Broken Bones or Bleeding Blood	3.10	6.20
		Fatal	1.55	1.55
	After	Broken Bones or Bleeding Blood	1.27	0.00
		Fatal	0.00	0.00
Monthly Crash Rate Distribution by Direction During Construction (Crashes per 100 MVMT)				
	Month with the Highest Crash Rates		Jun 2003 (6.20)	Jun 2002 (4.65)
	Month with the Lowest Crash Rates		Jul. 2002, Jan. and Mar. 2003 (0.00)	Apr. 2002, Apr. and May 2003 (0.00)

Table C-41 summarizes the analysis results between crash rates and other factors such as light condition, traffic control measure, alignment, weather condition, surface condition, etc. The directional crash rate analysis by severity and light condition during construction showed that 'fatal' and 'broken bones or bleeding blood' crashes happened in the 'daylight' light condition in the northbound direction, while those in the southbound direction took place in the 'dark street or highway not lighted' and the 'daylight' light conditions.

The directional crash rate analysis by analysis period and traffic control showed that crash trends related to the alignment are similar between southbound and northbound directions. In the three periods, the highest crash rates happened in the 'traffic lane marked' traffic control.

The directional crash rate analysis by analysis period and alignment showed that the trends for both directions concerning the relationship between alignment and the highest crash rates were the same except before construction. The highest crash rates in both directions happened in the 'straight and level' sections during and after construction. The highest crash rates before construction happened in the 'grade straight' section for the northbound direction and in the 'straight and level' section for the southbound direction.

The directional crash rate analysis by analysis period and weather condition showed that weather conditions with the highest and lowest crash rates were the same in both directions. The weather condition with the highest crash rates in the three periods was 'clear'.

The directional crash rate analysis by analysis period and surface condition shared similar results with the weather condition analysis. The surface condition with the highest crash rates in the three periods was in the 'dry' condition.

The analysis of the number of crashes by crash type during construction showed that the crash type with the highest crash rates in both directions in all the construction periods was a multi-vehicle crash type (MV-MV).

Table C-41 Summary of Other Analysis Results by Direction (I-15 Study Site)

Main Factor	Contents	Direction	
		Northbound	Southbound
Directional Crash Rate Analysis by Severity and Light Condition during Construction (Crashes per 100 MVMT)			
	Broken Bones or Bleeding Blood	Daylight (3.34)	Daylight (5.01), Dark Street or Highway Not Lighted (1.67)
	Fatal	Daylight (1.67)	Dark Street or Highway Not Lighted (1.67)
Directional Crash Rate Analysis by Analysis Period and Traffic Control (Crashes per 100 MVMT)			
Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (36.87)	Traffic Lanes Marked (36.87)
Before	Traffic Control with the Lowest Crash Rates	No Passing Lanes, Traffic Signal, Flagman, Construction or Work Area (0.00)	No Passing Lanes, Flagman, Construction or Work Area (0.00)
During	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (13.94)	Traffic Lanes Marked (20.14)
During	Traffic Control with the Lowest Crash Rates	No Passing Lanes, Traffic Signal, No Control Present (0.00)	No Passing Lanes, Traffic Signal, Flagman (0.00)
After	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (16.54)	Traffic Lanes Marked (19.09)
After	Traffic Control with the Lowest Crash Rates	The Others Except Traffic Lane Marked (0.00)	The Others Except Traffic Lane Marked and Traffic Signal (0.00)
	Traffic Control with the Largest Increase in Crash Rates From Before To After	-	Traffic Signal (0.00→1.27)
	Traffic Control with the Largest Decrease in Crash Rates From Before To After	Traffic Lanes Marked (36.87→16.54)	Traffic Lanes Marked (36.87→19.09)
Directional Crash Rate Analysis by Analysis Period and Alignment (Crashes per 100 MVMT)			
Before	Alignment with the Highest Crash Rates	Grade Straight (18.09)	Straight and Level (24.35)
Before	Alignment with the Lowest Crash Rates	Curve Grade, Hillcrest Straight (0.00)	Curve Hillcrest, Hillcrest Straight (0.00)
During	Alignment with the Highest Crash Rates	Straight and Level (15.49)	Straight and Level (17.04)
During	Alignment with the Lowest Crash Rates	Curve Hillcrest, Hillcrest Straight (0.00)	Curve Hillcrest, Hillcrest Straight (0.00)
After	Alignment with the Highest Crash Rates	Straight and Level (10.18)	Straight and Level (14.00)
After	Alignment with the Lowest Crash Rates	Curve Hillcrest, Hillcrest Straight (0.00)	Grade Straight, Curve Hillcrest, Hillcrest Straight (0.00)
	Alignment with the Largest Increase in Crash Rates From Before To After	Curve Grade (0.00→1.27)	Curve Grade (1.39→3.82)
	Alignment with the Largest Decrease in Crash Rates From Before To After	Grade Straight (18.09→5.09)	Grade Straight (12.52→0.00)

Table C-41 Continued

Main Factor		Contents	Direction: Northbound	Direction: Southbound
Directional Crash Rate Analysis by Analysis Period and Weather Condition (Crashes per 100 MVMT)				
	Before	Weather Condition with the Highest Crash Rates	Clear (22.96)	Clear (25.04)
		Weather Condition with the Lowest Crash Rates	Mist, Windstorm (0.00)	Windstorm (0.00)
	During	Weather Condition with the Highest Crash Rates	Clear (26.34)	Clear (18.59)
		Weather Condition with the Lowest Crash Rates	Mist, Sleeting, Windstorm (0.00)	Mist, Raining, Windstorm (0.00)
	After	Weather Condition with the Highest Crash Rates	Clear (11.45)	Clear (14.00)
		Weather Condition with the Lowest Crash Rates	Mist, Raining, Windstorm, Sleeting (0.00)	Mist, Raining, Windstorm (0.00)
	Weather Condition with the Largest Increase in Crash Rates From Before To After		Cloudy (5.57→6.20)	Sleeting (0.70→1.27)
	Weather Condition with the Largest Decrease in Crash Rates From Before To After		Clear (22.96→11.45)	Clear (25.04→14.00)
Directional Crash Rate Analysis by Analysis Period and Surface Condition (Crashes per 100 MVMT)				
	Before	Surface Condition with the Highest Crash Rates	Dry (27.13)	Dry (27.13)
		Surface Condition with the Lowest Crash Rates	Muddy (0.70)	Muddy (0.00)
	During	Surface Condition with the Highest Crash Rates	Dry (30.99)	Dry (24.79)
		Surface Condition with the Lowest Crash Rates	Icy, Muddy (0.00)	Icy, Muddy (0.00)
	After	Surface Condition with the Highest Crash Rates	Dry (19.09)	Dry (16.54)
		Surface Condition with the Lowest Crash Rates	Snow, Wet, Muddy (0.00)	Icy, Muddy (0.00)
	Surface Condition with the Largest Increase in Crash Rates From Before To After		-	-
	Surface Condition with the Largest Decrease in Crash Rates From Before To After		Dry (27.13→19.09)	Dry (27.13→16.54)
Number of Crashes by Crash Types during Construction (Number of Crashes Involved Crash Type/ Total Number of Crashes)				
	The Highest Crash Type (Number of Crashes/Total Crashes)		MV-MV (7/24)	MV-MV (9/25)

C.2.5.3 Analyses by Construction Phase

Table C-42 summarizes the results of spatial and temporal analyses by construction phases on I-15. Among the three phases, Phase III had the longest time span of construction, but Phase II had the highest crash rate.

The temporal and spatial distribution analysis of crashes in the work zone by phase showed that the section from MP 207.0 to MP 208.0 had the highest crash rate in Phase I, while the section from MP 211.01 to MP 211.17 had the highest crash rates in Phase II and Phase III.

The crash rate analysis by severity and phase showed that the crash rate of 'broken blood or bleeding blood' increased as time proceeded from Phase I to Phase III. Phase III was the only phase that had 'fatal' crash rates and its rate was 6.73 crashes per 100 MVMT.

The crash rate analysis by day of the week and phase showed that Phase I and Phase II had the highest crash percentage share on weekdays, Tuesday and Thursday, respectively, while Phase III had the highest crash percentage share on Sundays.

In the crash rate analysis by light condition and phase, all phases had the highest crash rate in the 'daylight' condition. Also, the crash rate analysis by traffic control and phase showed that the highest crash rates involved a 'construction or work area' control in all three phases.

The crash rate analysis by alignment and phase showed that Phase I and Phase II had the highest crash rate in the 'grade straight' and 'straight and level' sections, respectively, while Phase III had the highest crash rates in the 'grade straight' and 'straight and level' sections.

The crash rate analysis by weather condition and phase showed that the weather conditions with the highest crash rate varied among the three phases; 'clear' condition for Phase I and Phase II, and 'cloudy' condition for Phase III. In the crash rate analysis by surface condition and phase, the highest crash rate happened in the same surface condition, that is, the 'dry' surface condition. The analysis of crash breakdown type by phase showed that 'MV-MV' crash involvement had the highest crash rate.

Table C-42 Summary of Spatial and Temporal Analysis Results by Construction Phase (I-15 Study Site)

Main Factor	Contents	Phase I	Phase II	Phase III
General Outline				
	Duration	Apr.2002-Aug.2002	Aug.2002-Nov.2002	Nov.2002-Jun.2003
	Main Construction Type	Inside Lane Construction	Dynamic Compaction	Inside Lane Construction
	Crashes per 100 MVMT	73.94	98.59	73.22
Temporal Spatial Distribution Analysis of Crashes in Work Zone by Phase (Crashes per 100 MVMT)				
	Section with the Highest Crash Rates	MP 207.01-208.00 (175.88)	MP 211.01-211.17 (488.54)	MP 211.01-211.17 (441.70)
	Section with the Lowest Crash Rates	MP 201.01-202.00 MP 204.01-205.00 (0.00)	MP 200.07-202.00, MP 204.01-207.00 (0.00)	MP 201.01-203.00 MP 205.01-207.00 (0.00)
Crash Analysis by Severity and Phase Direction; Higher Severe Crash Rates (Crashes per 100 MVMT)				
	Broken Bones or Bleeding Blood (BBBB)	5.28	7.04	12.73
	Fatal	0.00	0.00	6.73
Crash Rates by Day of the Week and Phase (Crashes per 100 MVMT)				
	Day with the Highest Crash Rates	Tuesday (21.13)	Thursday (20.17)	Sunday (22.28)
	Day with the Lowest Crash Rates	Monday, Friday (5.28)	Saturday, Sunday (0.00)	Thursday (0.00)
Crash Rates by Light Condition Phase (Crashes per 100 MVMT)				
	Light Condition with the Highest Crash Rate	Daylight (68.66)	Daylight (56.34)	Daylight (44.57)
	Light Condition with the Lowest Crash Rate	Dark Street or Highway Not Lighted, Dawn, Dusk (0.00)	Dark Street or Highway Lighted, Dawn, Dusk (0.00)	Dark Street or Highway Lighted, Dawn, Dusk (0.00)
Distribution of Crash Rates by Traffic Control Method and Phase (Crashes per 100 MVMT)				
	Traffic Control with the Highest Crash Rates	Construction or Work Area (52.82)	Construction or Work Area (77.46)	Construction or Work Area (50.93)
	Traffic Control with the Lowest Crash Rates	No Control Present, Flagman (0.00)	No Control Present, Flagman (0.00)	No Control Present, Flagman (3.18)
Crash Rates by Alignment and Phase (Crashes per 100 MVMT)				
	Alignment with the Highest Crash Rates	Grade Straight (31.69)	Straight and Level (56.34)	Grade Straight, Straight and Level (28.65)
	Alignment with the Lowest Crash Rates	Curve Hillcrest (0.00)	Curve Grade, Curve Hillcrest, Hillcrest Straight (0.00)	Curve Hillcrest, Hillcrest Straight (0.00)
Distribution of Crashes Rates by Weather Condition and Phase (Crashes per 100 MVMT)				
	Weather Condition with the Highest Crash Rates	Clear (42.25)	Clear (77.46)	Cloudy (35.02)
	Weather Condition with the Lowest Crash Rates	Snowing (0.00)	Fog, Raining (0.00)	Fog, Raining (0.00)
Distribution of Crash Rates by Surface Condition and Phase (Crashes per 100 MVMT)				
	Surface Condition with the Highest Crash Rates	Dry (58.10)	Dry (77.46)	Dry (47.35)
	Surface Condition with the Lowest Crash Rates	Snowy, Wet (5.28)	Snowy, Wet (7.04)	Wet (6.37)
Crash Breakdown Type by Phase (Number of Crashes Involved Crash Type/ Total Number of Crashes)				
	The Highest Crash Type	MV-MV (6/14)	MV-MV (5/19)	MV-MV (5/23)

C.2.5.4 Analyses for the Summer Months

Table C-43 summarizes the results of spatial and temporal analyses for the summer months on I-15. The analysis periods included June, July, and August from 1999 to 2004. Crash rates decreased as time proceeded from before construction to after construction. Note that no 'fatal' crashes took place after construction.

The crash rate analysis by severity for the summer months showed that 'broken bones or bleeding blood' and 'fatal' crashes took place before and during construction. The crash rates of 'broken bones or bleeding blood' and 'fatal' crashes decreased as time proceeded from before construction to during construction

The spatial and temporal crash rate comparison in the work zone for the summer months showed that the sections with the highest crash rates were between MP 205.01 and MP 206.00 during the before period, between MP 208.01 and MP 209.0 during the during period and between MP 202.01 and MP 203.00 during the after period.

The crash rate analysis by day of the week for the summer months showed that the highest crash rates happened on Wednesday in the before and after construction periods, while the highest crash rates happened on Friday and Sunday during construction. The largest increase in crash rate from before to after construction happened on Monday, while the largest decrease in crash rate from before to after construction happened on Thursday.

Table C-43 Summary of Spatial and Temporal Analysis Results for the Summer Months (I-15 Study Site)

Main Factor	Contents		
General Outline			
	Analysis Duration		June, July, Aug 2002 and June 2003
	Crash Rates per 100 MVMT	Before	200.35
		During	159.77
		After	61.84
Crash Rate Analysis by Severity for the Summer Months (Crashes per 100 MVMT)			
	Before	Broken Bones or Bleeding Blood (BBBB)	33.39
		Fatal	8.35
	During	Broken Bones or Bleeding Blood	21.79
		Fatal	7.26
	After	Broken Bones or Bleeding Blood	0.00
		Fatal	0.00
Spatial and Temporal Crash Rate Comparison in Work Zone for the Summer Months (Crashes per 100 MVMT)			
	Before	Section with the Highest Crash Rates	MP 205.01-206.00 (33.39)
		Section with the Lowest Crash Rates	MP 203.01-204.00 (0.00)
	During	Section with the Highest Crash Rates	MP 208.01-209.00 (43.57)
		Section with the Lowest Crash Rates	MP 200.07-202.00, MP 205.01-206.00 (0.00)
	After	Section with the Highest Crash Rates	MP 202.01-203.00 (20.61)
		Section with the Lowest Crash Rates	MP 200.07-202.00, MP 204.01-205.00, MP 206-01-208.00, MP 209.01-210.00 MP 211.01-211.17 (0.00)
	Section with the Largest Increase in Crash Rates From Before To After		MP 203.01-204.00 (0.00→6.87)
	Section with the Largest Decrease in Crash Rates From Before To After		MP 205.01-206.00 (33.39→6.87)
Crash Rate Analysis by Day of the Week for the Summer Months			
	Before	Day with the Highest Crash Rates	Wednesday
		Day with the Lowest Crash Rates	Saturday
	During	Day with the Highest Crash Rates	Friday, Sunday
		Day with the Lowest Crash Rates	Monday
	After	Day with the Highest Crash Rates	Wednesday
		Day with the Lowest Crash Rates	Sunday
	Day with the Largest Increase in Crash Rates From Before To After		Monday
	Day with the Largest Decrease in Crash Rates From Before To After		Thursday

Table C-44 summarizes the analysis results between crash rates for the summer months and other factors such as light condition, traffic control method, alignment, weather condition, surface condition, and involved crash type.

The crash rate analysis by light condition during construction for the summer months showed that the highest crash rates took place in the ‘daylight’ condition. The largest decrease in crash rates happened in the ‘dark street or highway not lighted’ condition.

The crash rate analysis by analysis period and traffic control for the summer months showed that most of the crashes took place in the ‘traffic lanes marked’ sections before construction. During construction, the highest crash rate was attributed to the ‘construction or work area’ sections. After construction, the ‘traffic lane marked’ sections again had the highest crash rate.

The crash rate analysis by analysis period and alignment for the summer months showed that the ‘straight and always level’ sections had the highest crash rate for before and after construction and the ‘grade straight’ sections during construction, while the ‘dip straight’ and ‘hillcrest straight’ sections had the lowest crash rate. After construction, the most improvement in the ‘grade straight’ sections was achieved as shown in Table C-44 with the highest decrease in crash rates in the ‘grade straight’ sections.

The crash rate analysis by analysis period and weather condition showed that the highest crash rates happened in the ‘clear’ weather condition in the three construction phases. Also, the crash rate analysis by analysis period and surface condition showed that the highest crash rates took place in the ‘dry’ surface condition.

The analysis of the number of crashes by crash type during construction showed that crashes involving the ‘ran-off roadway-right’ type had the highest crash number, with 7 crashes out of a total of 22 crashes.

Table C-44 Summary of Other Analysis Results For the Summer Months (I-15 Study Site)

Main Factor			Contents
Crash Rate Analysis by Light Condition for the summer months (Crashes per 100 MVMT)			
	Before	Light Condition with the Highest Crash Rates	Daylight (108.53)
		Light Condition with the Lowest Crash Rates	Dawn, Dusk (8.35)
	During	Light Condition with the Highest Crash Rates	Daylight (116.19)
		Light Condition with the Lowest Crash Rates	Dawn, Dusk (0.00)
	After	Light Condition with the Highest Crash Rates	Daylight (54.97)
		Light Condition with the Lowest Crash Rates	Dark street or Highway Lighted, Dawn, Dusk (0.00)
	Light Condition with the Largest Increase in Crash Rates From Before To After		-
	Light Condition with the Largest Decrease in Crash Rates From Before To After		Dark street or Highway Not Lighted (66.87→6.87
Crash Rate Analysis by Traffic Control for the Summer Months (Crashes per 100 MVMT)			
	Before	Traffic Control with the Highest Crash Rates	Traffic Lanes Marked (175.31)
		Traffic Control with the Lowest Crash Rates	Flagman, Construction or Work Area (0.00)
	During	Traffic Control with the Highest Crash Rates	Construction or Work Area (101.67)
		Traffic Control with the Lowest Crash Rates	No Control Present (0.00)
	After	Traffic Control with the Highest Crash Rates	Traffic Lane Marked (54.87)
		Traffic Control with the Lowest Crash Rates	No Control Present, Flagman, Construction or Work Area (0.00)
	Traffic Control with the Largest Increase in Crash Rates From Before To After		Flagman, Construction or Work Area (0.00→ 101.67→0.00)
	Traffic Control with the Largest Decrease in Crash Rates From Before To After		Traffic Lanes Marked (175.31→54.97)
Crash Rate Analysis by Alignment for the Summer Months (Crashes per 100 MVMT)			
	Before	Alignment with the Highest Crash Rates	Straight and Level (91.83)
		Alignment with the Lowest Crash Rates	Dip Straight, Hillcrest Straight (0.00)
	During	Alignment with the Highest Crash Rates	Grade Straight (72.63)
		Alignment with the Lowest Crash Rates	Dip Straight, Hillcrest Straight (0.00)
	After	Alignment with the Highest Crash Rates	Straight and Level (41.23)
		Alignment with the Lowest Crash Rates	Dip Straight, Hillcrest Straight, Curve Level, Curve Grade (0.00)
	Alignment with the Largest Increase in Crash Rates From Before To After		-
	Alignment with the Largest Decrease in Crash Rates From Before To After		Grade Straight (75.13→20.61)
Crashes Rate Analysis by Analysis Period and Weather Condition for the Summer Months (Crashes per 100 MVMT): No Changing (Clear and Cloudy)			
Crashes Rate Analysis by Analysis Period and Surface Condition for the Summer Months (Crashes per 100 MVMT): No Changing (Dry)			
Number of Crashes by Crash Types during Construction for the Summer Months (Number of Crashes of the Crash Type/ Total Number of Crashes)			
	The Highest Crash Type		Ran Off Roadway -Right (7/22)

Appendix D: Results of CATMOD Analysis of Other Contributors

D.1 Alignment

D.1.1 p-Value

Figure D-1 shows the maximum likelihood analysis variance by alignment (coded as r_c, road condition). All p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistically meaning. Please note that the func.class (functional class) variable shown in the maximum likelihood analysis of variance output means highway class.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	320.65	<.0001
sev	4	1376.88	<.0001
func_class*sev	12	219.01	<.0001
r_c	6	1720.68	<.0001
func_class*r_c	18	1240.89	<.0001
sev*r_c	22*	65.96	<.0001
Likelihood Ratio	52	91.40	0.0006

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-1 P-Value for Alignment(r_c)

D.1.2 Main Contributors to Crashes by Alignment Category

Based on the p-values shown in Figure D-1, comparison of alignment conditions by highway class and crash severity level can be done. Table D-1 compares the main contributors of crashes by alignment. The primary contributor means that the highest number of crashes took place in the special alignment condition mentioned in the table laid out in the functional class by crash severity matrix. The secondary contributor means that the second highest number of crashes took place in the special alignment condition by highway class and by the crash severity.

As shown in Table D-1, the primary contributor of the special alignment condition by highway class and crash severity level is the 'straight' alignment section in all highway classes and crash severity levels. The secondary contributor of the special alignment condition by highway class and crash severity level varies as shown in the table. Most of the secondary contributors are 'grade straight' except in the 'fatal' severity level, whose second contributor is the 'curve' section.

Table D-1 Main Contributors of Crashes (Alignment)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Straight	Straight	Straight	Straight	Straight
	Secondary	Grade Straight	Grade Straight	Straight Grade	Grade Straight	Curve Grade
UI	Primary	Straight	Straight	Straight	Straight	Straight
	Secondary	Grade Straight	Grade Straight	Straight Grade	Grade Straight	Curve Level
RNI	Primary	Straight	Straight	Straight	Straight	Straight
	Secondary	Grade Straight	Grade Straight	Straight Grade	Grade Straight	Grade Straight
UNI	Primary	Straight	Straight	Straight	Straight	Straight
	Secondary	Grade Straight	Grade Straight	Straight Grade	Grade Straight	Curve Level

D.2 Light Condition

D.2.1 p-Value

Figure D-2 shows the maximum likelihood analysis of variance by light condition. All p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
func_class	3	377.69	<.0001
sev	4	1622.86	<.0001
func_class*sev	12	226.02	<.0001
light_cond	3	1135.23	<.0001
func_class*light_cond	9	179.78	<.0001
sev*light_cond	12	109.16	<.0001
Likelihood Ratio	29	56.52	0.0016

Figure D-2 P-Value for Light Condition

D.2.2 Main Contributors to Crashes by Lighting Category

Based on the p-values shown in Figure D-2, comparison of light conditions by highway class and crash severity level can be made. Table D-2 shows the results. The primary contributor is highway class and severity level combinations. The secondary contributor means that the second highest number of crashes took place in the special light condition in highway class and severity level combinations.

As shown in Table D-2, the primary contributor of the light condition by functional class and crash severity level is the 'daylight' light condition. The secondary contributor of the alignment condition by functional class and crash severity is the 'darkness' light condition. The reason why the primary contributor is 'daylight' is that the highest exposure to driving happens during the day.

Table D-2 Main Contributors of Crashes (Light Condition)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Daylight	Daylight	Daylight	Daylight	Daylight
	Secondary	Darkness	Darkness	Darkness	Darkness	Darkness
UI	Primary	Daylight	Daylight	Daylight	Daylight	Daylight
	Secondary	Darkness	Darkness	Darkness	Darkness	Darkness
RNI	Primary	Daylight	Daylight	Daylight	Daylight	Daylight
	Secondary	Darkness	Darkness	Darkness	Darkness	Darkness
UNI	Primary	Daylight	Daylight	Daylight	Daylight	Daylight
	Secondary	Darkness	Darkness	Darkness	Darkness	Darkness

D.3 Number of Vehicles Involved in Crash

D.3.1 p-Value

Figure D-3 shows the maximum likelihood analysis of variance by the number of vehicles related to a crash. All p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance

Source	DF	Chi-Square	Pr > ChiSq
func_class	3	472.87	<.0001
sev	4	1882.54	<.0001
func_class*sev	12	271.87	<.0001
num_veh	4	657.43	<.0001
func_class*num_veh	12	952.84	<.0001
sev*num_veh	15*	1535.16	<.0001
Likelihood Ratio	38	143.54	<.0001

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-3 p-Value for Number of Vehicle

D.3.2 Main Contributors of Crashes

Since all the p-values are less than 0.05, comparison of the number of vehicles involved in a crash by highway class and crash severity level can be done. Table D-3 shows the results. The primary contributor shows the highest number of crashes involved in a crash by highway class and crash severity level. The secondary contributor shows the second highest number of crashes by highway class and crash severity level.

As shown in Table D-3, the primary and secondary contributors vary by highway class and crash severity level. The primary contributors of all highway classes and severity levels were two vehicles except at high severity levels on Urban Interstate highways, such as ‘bruises and abrasion’, ‘broken bones or bleeding blood’, and ‘fatal’ crashes. The secondary contributors have trends similar to the primary contributors with the exception of Non-Interstate highways.

Table D-3 Main Contributors of Crashes (Number of Vehicle)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	2	2	1	1	1
	Secondary	1	1	2	2	2
UI	Primary	2	2	2	2	2
	Secondary	3	3	3	3	4
RNI	Primary	2	2	2	2	2
	Secondary	3	3	3	1	1
UNI	Primary	2	2	2	2	2
	Secondary	3	3	3	3	1

D.4 Main Contributor of Crash

D.4.1 p-Value

Figure D-4 shows the maximum likelihood analysis of variance by main contributor of crash (prime_cont). The p-values of the highway class and the likelihood ratio are greater than 0.05. To make matters worse, there are no other p-values to compare the main contributors of crash for highway class and severity level combinations. Therefore, no statistically meaningful comparison can be made for highway class and crash severity level combinations.

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
func_class	3	1.27	0.7358
sev	4	13.89	0.0077
func_class*sev	12	210.16	<.0001
prime_cont	36*	.	.
func_class*prime_cont	92*	.	.
sev*prime_cont	89*	.	.
Likelihood Ratio	148	169.92	0.1049

Figure D-4 p-Value for Main Contributor

D.5 Collision Type

D.5.1 p-Value

Figure D-5 shows the maximum likelihood analysis of variance by collision type. All p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
func_class	3	73.55	<.0001
sev	4	577.41	<.0001
func_class*sev	12	187.99	<.0001
coll_type	6	1053.21	<.0001
func_class*coll_type	17*	1947.17	<.0001
sev*coll_type	19*	688.19	<.0001
Likelihood Ratio	32	124.14	<.0001

Figure D-5 p-Value for Collision Type

D.5.2 Main Contributors to Crashes

Table D-4 shows the primary and secondary contributors; they vary widely in highway class and crash severity level combinations.

The primary contributor of collision type was the ‘same direction’ collision type followed by ‘single vehicle’ and ‘opposite turns’. The secondary contributor was ‘single vehicle’ followed by ‘opposite turns’ and ‘same direction’

Table D-4 Main Contributors of Crashes (Collision Type)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Same Direction	Same Direction	Single Vehicle	Single Vehicle	Single Vehicle
	Secondary	Single Vehicle	Single Vehicle	Same Direction	Same Direction	Opposite Turns
UI	Primary	Same Direction	Same Direction	Same Direction	Same Direction	Same Direction
	Secondary	Single Vehicle	Single Vehicle	Single Vehicle	Opposite Turns	Single Vehicle
RNI	Primary	Same Direction	Same Direction	Same Direction	Single Vehicle	Opposite Turns
	Secondary	Single Vehicle	Opposite Turns	Single Vehicle	Opposite Turns	Single Vehicle
UNI	Primary	Same Direction	Same Direction	Same Direction	Same Direction	Opposite Turns
	Secondary	Single Vehicle	Opposite Turns	Opposite Turns	Opposite Turns	Single Vehicle

D.6 Day of the Week

D.6.1 p-Value

Figure D-6 shows the maximum likelihood analysis variance by the day of the week. All p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	516.34	<.0001
sev	4	7130.69	<.0001
func_class*sev	12	174.33	<.0001
day	6	71.40	<.0001
func_class*day	18	198.27	<.0001
sev*day	24	115.28	<.0001
Likelihood Ratio	64	148.09	<.0001

Figure D-6 p-Value for Day of the Week

D.6.2 Main Contributors to Crashes

As shown in Table D-5, the primary and secondary contributors vary according to the collision type by highway class and crash severity level. No special trends on the main contributors of crashes by the day of the week were found. Only in the highest severity level, did the most 'fatal' crash happen on weekends on Rural Interstate highways and at mid-week on Urban Non-Interstate highways.

Table D-5 Main Contributors of Crashes (Day of the Week)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Friday	Friday	Monday	Thursday	Saturday
	Secondary	Monday	Thursday	Friday/ Sunday	Sunday	Sunday
UI	Primary	Saturday	Friday	Friday	Tuesday	Friday
	Secondary	Wednesday	Thursday	Thursday	Thursday	Tuesday
RNI	Primary	Wednesday	Tuesday/ Wednesday	Wednesday	Thursday	Saturday
	Secondary	Thursday	Thursday	Friday	Wednesday	Sunday
UNI	Primary	Wednesday	Tuesday	Wednesday	Saturday	Wednesday
	Secondary	Tuesday	Wednesday	Friday	Thursday	Monday/ Thursday

D.7 Surface Condition

D.7.1 p-Value

Figure D-7 shows the maximum likelihood analysis of variance by the day of the week. Almost all the p-values are less than 0.05 with the exception of the highway functional class. Even though the p-value for intra-comparison of the highway class is 0.2078, the comparison of inter- and intra-categories has statistical meaning because there was no need to have the comparison of highway classes, that is to say, comparison of one category of surface condition with other category of surface condition can be made.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	4.55	0.2078
sev	4	319.09	<.0001
func_class*sev	12	225.18	<.0001
surf_cond	5	1406.82	<.0001
func_class*surf_cond	14*	132.47	<.0001
sev*surf_cond	16*	68.43	<.0001
Likelihood Ratio	28	52.02	0.0038

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-7 p-Value for Surface Condition

D.7.2 Main Contributors to Crashes

As shown in Table D-6, the primary contributor of the surface condition by highway class and crash severity level is the ‘dry’ surface condition. The secondary contributor of the surface condition by highway class and crash severity level varies for highway class and severity level combinations. Most of the secondary contributor is the 'wet' condition except in the 'bruises and abrasion' severity level in the Rural Interstate highway class ('snowy' surface condition) and in the 'fatal' severity level in the Rural Non-Interstate highway class ('icy' surface condition). The main contributors for the surface condition are closely related to the weather condition and the exposure ratio of total surface condition.

Table D-6 Main Contributors of Crashes (Surface Condition)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Dry	Dry	Dry	Dry	Dry
	Secondary	Wet	Wet	Snowy	Wet	Wet
UI	Primary	Dry	Dry	Dry	Dry	Dry
	Secondary	Wet	Wet	Wet	Wet	Wet
RNI	Primary	Dry	Dry	Dry	Dry	Dry
	Secondary	Wet	Wet	Wet	Wet	Icy
UNI	Primary	Dry	Dry	Dry	Dry	Dry
	Secondary	Wet	Wet	Wet	Wet	

D.8 Weather Condition

D.8.1 p-Value

Figure D-8 shows the maximum likelihood analysis variance by the weather condition. All the p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	DF	Chi-Square	Pr > ChiSq
func_class	3	72.83	<.0001
sev	4	71.72	<.0001
func_class*sev	12	225.69	<.0001
weather	8	1263.96	<.0001
func_class*weather	20*	152.21	<.0001
sev*weather	23*	96.26	<.0001
Likelihood Ratio	34	69.48	0.0003

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-8 p-Value for Weather Condition

D.8.2 Main Contributors to Crashes

As shown in Table D-7, the primary and secondary contributors of the surface condition by highway class and crash severity level are the ‘clear’ surface condition and the ‘cloudy’ surface condition, respectively. There are no special contributors of weather condition except the ‘clear’ and ‘cloudy’ weather conditions. The only exception is all ‘fatal’ crashes in Non-Interstate highways happened in the ‘dry’ weather condition.

Table D-7 Main Contributors of Crashes (Weather Condition)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	Clear	Clear	Clear	Clear	Clear
	Secondary	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy
UI	Primary	Clear	Clear	Clear	Clear	Clear
	Secondary	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy
RNI	Primary	Clear	Clear	Clear	Clear	Clear
	Secondary	Cloudy	Cloudy	Cloudy	Cloudy	-
UNI	Primary	Clear	Clear	Clear	Clear	Clear
	Secondary	Cloudy	Cloudy	Cloudy	Cloudy	-

D.9 Crash Occurrence Time

D.9.1 p-Value

Figure D-9 shows the maximum likelihood analysis of variance by crash occurrence time. All the p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	652.93	<.0001
sev	4	5793.06	<.0001
func_class*sev	12	222.50	<.0001
time2	4	950.36	<.0001
func_class*time2	12	474.36	<.0001
sev*time2	16	129.32	<.0001
Likelihood Ratio	43	129.14	<.0001

Figure D-9 p-Value for Crash Occurrence Time

D.9.2 Main Contributors of Crashes

As shown in Table D-8, the primary contributor of the crash occurrence time zone by highway class and crash severity level is the ‘9:00 AM to 5:00 PM’ time zone. The secondary contributor of the crash occurrence time zone by highway class and crash severity level varies among the functional class and severity level combination. All of the second crash occurrence time zones are ‘5:00 PM to 7:00 PM’ except in the higher severity levels on Rural and Urban Interstate highways. The fact that most of crash occurrences took place in the ‘9:00 AM to 5:00 PM’ time zone means that the majority of crashes happened during active construction periods.

Table D-8 Main Contributors of Crashes (Crash Occurrence Time)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	9AM – 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM
	Secondary	5PM – 7PM	5PM - 7PM	7PM-10PM	10PM-7AM	10PM-7AM
UI	Primary	9AM – 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM
	Secondary	5PM – 7PM	5PM - 7PM	5PM - 7PM	10PM-7AM	10PM-7AM
RNI	Primary	9AM – 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM
	Secondary	5PM – 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM	10PM-7AM
UNI	Primary	9AM – 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM	9AM - 5PM
	Secondary	5PM – 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM	5PM - 7PM

D.10 Estimated Speed

D.10.1 p-Value

Figure D-10 shows the maximum likelihood analysis of variance by the estimated speed. All the p-values except the p-values of the highway class are less than 0.05. Even though the p-value of intra-comparison of the highway class is 0.69, the comparison of inter- and intra-categories of estimated speed has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	1.46	0.6911
sev	4	209.19	<.0001
func_class*sev	12	195.65	<.0001
est_speed	18	246.31	<.0001
func_class*est_speed	48*	2599.46	<.0001
sev*est_speed	64*	296.75	<.0001
Likelihood Ratio	129	156.46	0.0503

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-10 P-Value for Estimated Speed

D.10.2 Main Contributors of Crashes

As shown in Table D-9, the primary and secondary contributors of the special estimated speed zone by highway class and crash severity level vary depending on the combination of highway class and crash severity level. Note that the trend of the primary contributor and the secondary contributor of the estimated speed by highway class and crash severity level are different between the two highway groups, Interstate and Non-Interstate highways. The primary contributor of the estimated speed on Interstate highways was the higher estimated speed, '50 mph to 65 mph'. While the main contributor of the estimated speed on Non-Interstate highways was the lower estimated speed, from '5 mph to 10 mph' except for some highway class and crash severity level combinations.

Table D-9 Main Contributors of Crashes (Estimated Speed)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	55mph	55mph	55mph	65mph	55mph
	Secondary	50mph	50mph	65mph	55mph	65mph/ 75mph
UI	Primary	55mph	55mph	55mph	55mph	55mph
	Secondary	50mph	50mph	50mph	65mph	45mph/ 50mph
RNI	Primary	5mph	5mph	5mph	5mph	40mph
	Secondary	10mph	30mph	60mph	50mph	50mph
UNI	Primary	5mph	5mph	5mph	5mph	5mph/ 45mph
	Secondary	10mph	10mph	10mph	30mph	30mph/ 65mph

D.11 Crash Type

D.11.1 p-Value

Figure D-11 shows the maximum likelihood analysis of variance by crash type. All the p-values are less than 0.05. Therefore, the comparison of inter- and intra-categories has statistical meaning.

Maximum Likelihood Analysis of Variance			
Source	**DF**	**Chi-Square**	**Pr > ChiSq**
func_class	3	10.16	0.0173
sev	4	46.18	<.0001
func_class*sev	12	159.11	<.0001
accident_type	9	2323.48	<.0001
func_class*accident_type	23*	1248.59	<.0001
sev*accident_type	31*	597.06	<.0001
Likelihood Ratio	55	108.24	<.0001

Note: Effects marked with '*' contain one or more redundant or restricted parameters.

Figure D-11 P-Value for Crash Type

D.11.2 Main Contributors of Crashes

Since all the p-values except the highway class have a value less than 0.05 as shown in Figure D-11, crash type by the functional class and crash severity level can be compared.

As shown in Table D-10, the primary and secondary contributors of the special estimated speed zone by highway class and crash severity level vary between highway class and crash severity level combinations. Most of the primary contributor was 'MV-MV' crash type, except in the higher crash severity level in Rural Interstate highway where the 'ran off road' crash type was the primary contributor.

The secondary contributor varied for the four highway classes. Secondary contributors in Rural highways were 'ran off road' and 'MV-MV' crash types while those in Urban highways were 'MV-fixed object', MV-pedestrian', and 'ran off road crash types.

Table D-10 Main Contributors of Crashes (Crash Type)

Highway Class	Contributor	Crash Severity				
		No Injury	Possible Injury	Bruises and Abrasion	BBBB	Fatal
RI	Primary	MV-MV	MV-MV	MV-MV	Ran Off Road	Ran Off Road
	Secondary	Ran Off Road	Ran Off Road	Ran Off Road	MV-MV	MV-MV
UI	Primary	MV-MV	MV-MV	MV-MV	MV-MV	MV-MV
	Secondary	MV-Fixed Object	MV-Fixed Object	MV-Fixed Object	MV-Fixed Object	Ran Off Road
RNI	Primary	MV-MV	MV-MV	MV-MV	MV-MV	MV-MV
	Secondary	Ran Off Road	Ran Off Road	Ran Off Road	Ran Off Road	Ran Off Road
UNI	Primary	MV-MV	MV-MV	MV-MV	MV-MV	MV-MV
	Secondary	MV-Fixed Object	MV-Fixed Object	MV-Pedestrian	Ran Off Road	Ran Off Road